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Proceedings of the
Sixth Pacific Science Congress
of the
Pacific Science Association

HELD AT THE UNIVERSITY OF CALIFORNIA, BERKELEY
STANFORD UNIVERSITY, AND SAN FRANCISCO
JULY 24TH TO AUGUST 12TH, 1939

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THOMAS G. THOMPSON, *Chairman*

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REPORT OF THE CHAIRMAN

By Thomas G. Thompson

Authorization of the Committee

At the Third Pan-Pacific Science Congress, held in Tokyo in 1926, the following resolution was passed:

> I. That the President of the Administrative Council of the Pacific Science Association appoint the Chairman of the Committee on the Oceanography of the Pacific and that the appropriate scientific body in each country represented in the Association appoint for the International Committee a member who shall be the chairman of a National Committee for his country.
>
> II. That at least three subcommittees be formed on (*a*) physical and chemical oceanography; (*b*) fundamental marine biology; (*c*) fisheries technology.
>
> III. That the closest possible relations be cultivated between the different National Committees and between the members of the special subcommittees for the different countries; that they submit their respective programs one to another, seek suggestions and advice regarding the different features of their work, and endeavor to bring about the greatest degree of standardization and coördination; and that the proceedings of the different National Committees and subcommittees be reported to the International Chairman, who shall submit a general report to the Pacific Science Association.
>
> IV. That the work of the committee be conducted with the intent of establishment for the Pacific an institution similar to the North Atlantic International Council for the Exploration of the Sea.

After the adoption of this resolution, Professor Sakurai, the president of the Third Pan-Pacific Science Congress, honored Dr. T. Wayland Vaughan, then director of the Scripps Institution of Oceanography, by naming him chairman. Dr. Vaughan served in this capacity for the Fourth Pacific Science Congress, held in Batavia, Netherlands Indies, and for the Fifth Pacific Science Congress, in Vancouver, Canada. The monumental and thorough reports of Dr. Vaughan and his committee comprise important parts of the published proceedings of both these Congresses.

At the Fifth Pacific Science Congress the following resolution was passed:

> *Whereas,* the study of fisheries in their relation to the ocean has always been considered a part of the field of oceanography; and
>
> *Whereas,* the stimulus to many oceanographic investigations has come from the desire to solve fishery problems;
>
> *Resolved,* at the Fifth Pacific Science Congress that a subcommittee on Fisheries be added to the subcommittees under the Committee on the Oceanography of the Pacific and that the titles of the five subcommittees be as follows: (1) Physical and Chemical Oceanography; (2) Marine Biology; (3) Fisheries; (4) Fisheries Technology; (5) Corals and Coral Reefs.

As a result of this resolution, which authorized the establishment of a committee on fisheries, thus making provision for the study of fisheries on a more extensive scale than had previously been contemplated, the former standing committee on tropical fishes was discontinued.

Shortly after the close of the Fifth Pacific Science Congress, Dr. Vaughan retired as director of the Scripps Institution of Oceanography. Because of ill health he was obliged to relinquish practically all of his very active committee work. Accordingly, the Administrative Council of the Pacific Science Association paid me the honor of naming me chairman of the International Committee on the Oceanography of the Pacific.

Organization for the Sixth Pacific Science Congress

The vicissitudes and uncertainties of the proposed Sixth Pacific Science Congress are well known. Early last fall, the chairman of this committee was formally notified of the decision to hold the present Congress in the United States. It was not until January of the present year that the formal invitations to participate in this Congress were actually mailed by representatives of the

United States Government to the several countries. Much time must necessarily elapse before receiving replies to letters concerning the details of the Congress, when addressed through official channels. This procedure, coupled with the great distances to be covered and the spirit of political unrest in some parts of the Pacific area, has been a marked handicap in the preparation of the present report and in the symposia prepared by the chairmen of the several subcommittees. To facilitate matters, direct contact was accordingly made with some of the leading scientists representing many of the branches of oceanography in the several countries.

At the Fifth Pacific Science Congress, two additional subcommittees were recommended as part of the International Committee. One of these subcommittees—that dealing with coral reefs—has been organized, but the reports and programs of this committee will appear under the geological section of this Congress. For convenience, the subcommittees on fisheries technology and fisheries have been combined for the present meeting.

Many of the advances in our knowledge of the waters of the Pacific and the life contained therein will be detailed in the symposia that have been arranged by the chairmen of the several subcommittees.

Because of the great distances involved and the short time for planning for the Sixth Congress, the chairman of the International Committee, with due approval, asked the National Research Council of the United States to appoint a special committee to arrange the details of the symposia of the Congress. The committee appointed consisted of Martin W. Johnson, H. A. Marmer, Robert C. Miller, H. U. Sverdrup, W. F. Thompson, and Thomas G. Thompson, chairman. Members of this committee were placed in charge of subcommittees to arrange for symposia as follows:

Physical and chemical oceanography, H. U. Sverdrup, chairman.

Fisheries and fisheries technology, W. F. Thompson, chairman; Harry A. Dunlop, Roger W. Harrison, George S. Myers, Paul R. Needham, W. L. Scofield.

Marine biology, Robert C. Miller, chairman; Martin W. Johnson, co-chairman; Frederick A. Davidson, C. McLean Fraser, Trevor Kincaid, S. F. Light, Irene A. McCulloch.

Resolutions of the Fifth Pacific Science Congress

It is fitting at this time that a brief account be given of the actions taken on some of the resolutions passed by the Fifth Pacific Science Congress.

RESOLUTION NO. 9

Reporting of Oceanographical Data

Whereas, oceanographic chemists have long been aware of the confusion and unnecessary labor resulting from the existing practice of reporting chemical data for sea water in various different terms, many of which are illogical and misleading;

Resolved, That the Fifth Pacific Science Congress urge the adoption of a uniform system of reporting chemical data for sea water and that chlorinity be used as an index of the total dissolved solids in sea water.

The International Association of Physical Oceanography has assumed a major place in the science of physical oceanography. Practically all institutions throughout the world primarily interested in this subject are affiliated with the Association. Most of the nations of the world contribute financially to the support of the International Union of Geodesy and Geophysics, of which the International Association of Physical Oceanography forms one of six sections. Under the able leadership of scientists like Professor Martin Knudsen and Professor Bjorn Helland-Hansen, much has been accomplished by this Association.

It is, therefore, recommended that any attempts at standardization in the methods of technique of physical and chemical oceanography by this Congress be in accord with the recommendations of the International Association. The International Committee on the Oceanography of the Pacific Science Association is represented in the International Association of Physical Oceanography. At the Sixth General Assembly, held at Edinburgh in 1936, a special committee on chemical and physical methods and units was appointed, consisting of Professor Bjorn Helland-Hansen of Norway, chairman; Dr. J. P. Jacobsen of Denmark, and Dr. Thomas G. Thompson of the United States. [This committee was to make its first report at the Seventh General Assembly, at Washington, in September, 1939.]

RESOLUTION NO. 10

CARTE BATHYMÉTRIQUE GÉNÉRALE DES OCÉANS

Whereas, the International Hydrographic Bureau at Monaco is rendering valuable service to oceanography and geology by its endeavor to prepare and publish a revised edition of the Carte Bathymétrique Générale des Océans; and

Whereas, the preparation of the sheets to be reproduced as parts of the Carte Bathymétrique is retarded because of lack of sufficient funds to employ more than one draughtsman;

Resolved, That the Fifth Pacific Science Congress express its commendation of the International Hydrographic Bureau for its efforts to prepare and publish a revised edition of said Carte, and at the same time express the hope that sufficient funds may be procured for the employment of necessary additional assistance to expedite the preparation of the revised sheets for the printer.

Through the consistent efforts of the previous chairman of this committee, Dr. T. Wayland Vaughan, sufficient funds have been provided for the publication of the revised edition of the Carte Bathymétrique Générale des Océans.

RESOLUTION NO. 11

THE NONMAGNETIC R. R. S. "RESEARCH"

Resolved, That the Congress consider it of the utmost importance that the *Carnegie* be replaced at the earliest possible date in order that the magnetic, electric, and oceanographic work in which it was so admirably engaged, be continued, and that in the design of the new vessel ample provision be made for a broad program of geophysical investigations, including oceanography and meteorology as well as terrestrial magnetism and atmospheric electricity similar to that carried out on the last trip of the *Carnegie.*

Great Britain has assumed the responsibility of building a nonmagnetic vessel which will continue the very important work conducted by the *Carnegie.* A brief description of this new vessel is given below, the information being obtained from an article recently published by Admiral J. A. Edgell in *Terrestrial Magnetism and Atmospheric Electricity* for December, 1938.

A nonmagnetic vessel, the *Research,* is being built by the British Admiralty to continue the magnetic survey of the oceans inaugurated by the Carnegie Institution of Washington through its Department of Terrestrial Magnetism and carried on by the nonmagnetic vessel, *Carnegie,* from 1909 until her destruction by explosion and fire in November, 1929. The magnetic charts issued by the hydrographic services of the various countries have been based in increasing degree on data obtained by the *Carnegie,* but serious gaps in available data and the absence of information regarding the secular change in certain regions render imperative the resumption of the interrupted oceanic survey both from theoretical and practical considerations.

The construction of the *Research* was authorized, and the keel was laid September 9, 1937. Since that time good progress has been made. In order to assist in designing the vessel and her instrumental equipment, the Carnegie Institution of Washington, upon invitation of the Admiralty, made arrangements that William J. Peters, first commander of the *Carnegie* and designer of many of the special and improved types of magnetic instruments used at sea, spend a year in London as consultant on the design of the new vessel and of her special instruments. In addition, all information regarding the *Carnegie* was placed at the disposal of the British Admiralty, thus facilitating greatly the design of the new vessel.

The construction of such a nonmagnetic vessel obviously presents many problems to the builder, who must substitute nonmagnetic metals for all magnetic materials. One of the chief difficulties encountered has been the exclusion of iron and steel from the auxiliary Diesel oil engines. These are 160-horsepower, four-cylinder, two-stroke, direct air-reversing engines driving a two-blade feathering propeller. The difficulty has been solved by the extensive use of a bronze alloy, the crank shaft being made of a special nonmagnetic steel. Besides the main Diesel engines, there are two of 9 horsepower and one of 18 horsepower, for the dynamos, refrigerator (cold storage 120 cubic feet), air compressor, and winch for oceanographical work. The 160-horsepower Diesel engines will develop a speed of 6½ knots, and the oil capacity of 14 tons is sufficient for 3000 miles of travel. Electric current will be developed by two 4-kilowatt, 110-volt dynamos. How rigorously the nonmagnetic requirements have been met is evident from the fact that such items as iron nails in packing cases, tin food and cigarette containers, cooking utensils, cutlery, razor blades, drums for paint and lubricating oil, and typewriters, have been subjects of careful consideration.

The vessel is 142 feet, 6 inches, on the water line and has a moulded breadth of 34 feet, a maximum draught of 13 feet, 2 inches, and a load displacement of 770 tons. She will be brigantine rigged and will have a full sail area of about 12,000 square feet.

The keel, stem, and stern posts are of teak, the false keel is Canadian rock elm, and teak planks are laid on brass frames subdivided by eight metal watertight bulkheads. The hull is sheathed with copper. The ballast consists of 80 tons of lead, 20 tons on the keel, and 60 tons in the bilges. Anchors, cables, and wire for rigging are of aluminum bronze. Specially designed teak tanks for fresh water will have a capacity of 37½ tons. Accommodation is provided for 6 officers, 4 scientists, and 22 petty officers and men.

In addition to two magnetic observatories, one forward and one aft, there will be two laboratories, one each for atmospheric-electric and oceanographic research.

The instrumental equipment for magnetic observations will include: For declination, a marine collimating compass of the original design by W. J. Peters—the standard instrument on the *Carnegie* (this instrument will be mounted on the bridge deck over the chartroom); for determining the intensity of the force of the earth's field, a marine deflector as designed by L. A. Bauer and J. A. Fleming of the Carnegie Institution of Washington; and for inclination, a marine earth inductor, likewise of the design of the Carnegie Institution of Washington. A Smith portable magnetometer, a C. I. W. magnetometer-inductor, and a dip circle will also be carried for observations on shore and for instrumental comparisons at observatories.

The instruments which will be used in the atmospheric-electric work include: A potential-gradient recorder, a point-discharge apparatus, and a Wulf electrometer for standardizing the potential-gradient observations; a modified Ebert apparatus for ion counting; and a modified Wilson apparatus for determining the electrical conductivity of the atmosphere through measurements of the air-earth current.

The standard meteorological instruments for oceanic work will be provided to determine air temperatures, air pressures, dry and wet bulb temperatures, and sea temperatures. An Assmann psychrometer and an Aitken nuclei counter will be carried. Echo-sounding apparatus will be mounted in the oceanographic laboratory and an oceanographic winch will be provided for securing water samples, temperatures, and so on, at different depths. This winch will be driven from the auxiliary engines through line shafting and a fluid flywheel.

RESOLUTION NO. 12

Installation of Thermographs

Whereas, it is desirable for several kinds of scientific investigations, such as those of oceanic circulation and the interrelations between the sea and the atmosphere, to procure a larger number of detailed records of sea-surface temperatures than are at present being made; and

Whereas, it has been ascertained by experience that thermograph records of the temperature of the water in the condenser intake supply the desired information in a satisfactory way;

Resolved, That the Fifth Pacific Science Congress bring to the attention of the proper authorities in the different countries of the Pacific the need for having thermographs to record sea-surface temperatures, installed on such official vessels as those engaged in coastal surveys, naval transport, and in the carriage of fuel and supplies; *and further*

Resolved, That the authorities obtaining such records make provision for the use of said records by qualified investigators.

During the past six years the thermographic records of the temperatures of the waters have vastly increased and efforts have been made to assemble much of this data. It is thought, however, that this Congress could well reiterate the spirit of this resolution and bring it again to the attention of the authorities of the several countries.

RESOLUTION NO. 13

Echo Soundings

Whereas, much information relating to the configuration of the waters of the North Pacific Ocean has been collected by the navies of various countries on trans-Pacific and other voyages, by using echo-sounding devices, but as very few of the concomitant quantitative data, which are necessary for their reduction to precise measurements, have been obtained: *and*

Whereas, there is urgent scientific and economic need for the reduction of the echo-soundings which have already been made and the procurement of data relating to the seasonal variations in the temperature and salinity of the surface and subsurface waters of the North Pacific Ocean;

Resolved, That the Fifth Pacific Science Congress express its deep appreciation of the assistance rendered by the navies of various countries and the hope that such vessels as come under the administration of the various navies and are engaged in regular scheduled trans-Pacific and other voyages be fitted out at the earliest possible moment with such appliances as may be necessary for the recording of the desired quantitative data, and that the commanding officers be requested to obtain the required data; *and further*

Resolved, That this resolution be communicated to all the navies concerned.

Marked advances have been made in the development of the apparatus for taking echo soundings. Many of the naval vessels are equipped with apparatus which will permit the taking of deep as well as shallow soundings. Such data are made available to the International Hydrographic Office. However, most of the commercial boats, although equipped with echo-sounding apparatus, are limited in securing data because the apparatus generally installed records only to a little more than 100 fathoms.

RESOLUTION NO. 14

Soundings in the South Pacific and Antarctic Oceans

Whereas, notwithstanding the W-shaped line recently run by the *Discovery II* between New Zealand and southern South America, data on the configuration of the sea bottom in the South Pacific are deficient, especially in the area bounded by latitudes 20° and 55° S and longitudes 80° and 180° W; and

Whereas, it has been shown that naval vessels equipped with sonic-sounding apparatus can obtain valuable data on sea-bottom configuration;

Resolved, That the Fifth Pacific Science Congress recommend that those nations whose vessels may operate in the area indicated above, endeavor to have such vessels equipped with sonic-sounding apparatus, so that they may be utilized in obtaining additional data on sea-bottom configuration in the said area.

As far as can be learned, no vessels operating in this area have as yet made any reports, with the exception of H.M.S. *Discovery*.

RESOLUTION NO. 15

OCEANOGRAPHICAL INVESTIGATIONS IN THE VICINITY OF THE GALÁPAGOS ISLANDS

Whereas, the Galápagos Islands are situated in an area of great oceanographic and biological interest; *and*

Whereas, during recent years several expeditions have visited them primarily for making biological collections; *and*

Whereas, other expeditions may visit that region;

Resolved, That the Fifth Pacific Science Congress call attention to the desirability of intensive investigation of the physical, chemical, and biological oceanography in the vicinity of the Galápagos Islands; *and further*

Resolved, That the Fifth Pacific Science Congress express the hope that future expeditions will endeavor to obtain full oceanographic information on the region indicated in this resolution.

The only scientific expeditions that have operated in the area mentioned in this resolution have been those conducted by the *Velero III*. No attention was given to the physical and chemical characteristics of the waters of this region. The expeditions were primarily interested in the collection of biological specimens.

RESOLUTION NO. 16

WATERS OF THE NORTHEAST PACIFIC

Whereas, information on the configuration of the sea bottom, physical and chemical properties of the water, and the vertical distribution of marine organisms is markedly deficient for two areas in the northeast Pacific, namely:

(*a*) between the Hawaiian Islands and the Aleutian Islands, and

(*b*) within the triangle bounded by the North American coast and lines from the Hawaiian Islands to San Francisco and to Panama, respectively; *and*

Whereas, the information indicated is necessary to complete a general picture of oceanographic conditions in the northeast Pacific;

Resolved, That the Fifth Pacific Science Congress express the hope that vessels of the United States Government operating within the regions indicated (1) may run lines of sonic soundings, and (2) may be equipped to make appropriate vertical sections for ascertaining subsurface temperatures, collecting water samples, and studying the vertical subsurface distribution of organisms; *and further*

Resolved, That these resolutions be brought through appropriate channels to the attention of the governmental bureaus concerned.

The United States Navy has given excellent coöperation in securing information in the region designated in the resolution. For this purpose the Navy coöperated with the Scripps Institution of Oceanography and the Oceanographic Laboratories of the University of Washington. A section with the soundings, samplings, and temperature observations has been made by the Navy from the Aleutian Islands to the Hawaiian Islands, from the Aleutian Islands to the entrance of the Strait of Juan de Fuca, from the Strait of Juan de Fuca to the Hawaiian Islands, from the Hawaiian Islands to San Francisco, between the Hawaiian Islands and San Diego, and between the Hawaiian Islands and Panama. The data secured in several of these sections are incorporated in papers to be given in the symposia.

Some of these data, particularly for the more northerly sections, have been augmented by observations and samples collected through the efforts of Commander F. A. Zeusler of the United States Coast Guard.

RESOLUTION NO. 17

INTERNATIONAL FISHERIES COMMISSION

Whereas, the International Fisheries Commission, in its investigation of the halibut, has obtained much useful information on oceanographic conditions in the Gulf of Alaska; *and*

Whereas, this is useful for the study of the general oceanography of the Pacific, as well as for the proper understanding of the life conditions of the halibut;

Resolved, That the Fifth Pacific Science Congress urge the continuation and extension of the oceanographic program so ably initiated and conducted by the International Fisheries Commission.

The oceanographic work of the International Fisheries Commission has been continued each year since this resolution was passed by the Fifth Pacific Science Congress. Excellent progress has been made in the conservation of the halibut of the northern Pacific. Outlines of some of the important scientific findings of this Commission will be given in the symposia arranged by the subcommittee on fisheries. The functioning of this Commission offers an excellent example of what can be accomplished through international agreement and through coöperation of the industry with the Commission.

RESOLUTION NO. 18

INTERNATIONAL SALMON COMMISSION

Whereas, the salmon fisheries of the Pacific Coast of North America are of great economic value and of international interest, and present scientific problems of great importance with respect to the proper conservation of the species;

Resolved, That the Fifth Pacific Science Congress recommend to the governments especially concerned that the valuable investigations now under way be continued and that provision be made for international support and joint planning wherever these problems are of common interest, as is especially the case of those concerning the sockeye salmon of the Fraser River.

A favorable result can be reported for one of the resolutions passed, at the Fifth Pacific Science Congress, namely, that advocating conclusion of the convention between Canada and the United States having to do with the conservation of the sockeye salmon of the Fraser River.

This convention has been under discussion for thirty years by those interested in the great decline in the sockeye fishery. The convention was signed May 26, 1930, but ratifications were not exchanged until July 28, 1937. Three understandings were attached, the most important of which, from the present viewpoint, delayed regulation during an eight-year period of investigation.

The Commission established consists of three appointees from each country. It has met and organized, and a staff of scientists has been appointed. It is very similar in function and organization to the successful Halibut Commission; and it is pleasing to note that it has taken the same progressive view of its functions, inasmuch as it has committed itself to a policy of action only after scientific investigation, to the appointment of a scientific staff on a basis of technical qualifications, and is proceeding to a thorough program of research. The members are: A. L. Hager, chairman; B. M. Brennan, secretary; Charles E. Jackson, Edward W. Allen, Tom Reid, A. J. Whitmore. The director is Dr. W. F. Thompson. Among members of the staff are Dr. R. E. Foerster, Dr. J. L. Kask, Mr. M. B. Schaefer, and Mr. C. E. Atkinson. Others will be added this year.

It is expected that the research program will include an extensive study of the migration of adult and young salmon, of the races of sockeye both in the Fraser River and in the waters covered by the convention between 48° and 49° of latitude, a thorough statistical study of the catches, a survey of the Fraser River and the spawning grounds in its streams and lakes, and an exploration of the means of assisting propagation. The results of its first season's work include a successful tagging experiment, wherein, for the first time in salmon research, extensive recoveries of tags placed in salt water were made from the spawning grounds and at points en route, and an interesting experiment in the enumeration of the spawning population in a lake by tagging of a sample at the entrance. Good progress was made in a survey of the river and its runs by field parties, and in a compilation of the vast amount of data existent regarding the river and its runs in the past, contributed by the Canadian Department of Fisheries, the Fisheries Research Board of Canada during its valuable work on Fraser River sockeye under Dr. W. A. Clemens, the Washington State Department of Fisheries, and other governmental organizations.

The outstanding characteristic of the research program thus far is its thoroughness and the care used to cover all factors of importance. The future will undoubtedly see expansion of the program to the marine life of the salmon, and to study of the lakes and streams utilized by the sockeye.

Oceanographical Society of the Pacific

At the Third Pacific Science Congress held at Tokyo in 1926, it was recommended that steps be initiated toward the formation in the Pacific of an institution similar to the North Atlantic International Council for the Exploration of the Sea. Nothing was actually done in this regard until 1934, when, after correspondence and several conferences, Dr. T. Wayland Vaughan and Dr. Thomas G. Thompson organized the Oceanographic Society of the Pacific. Any scientist interested in the several phases of oceanography is eligible for membership in this organization.

At the present time the membership of the organization is composed of about one hundred scientists residing on the Pacific coast of Canada and the United States. Meetings have been held yearly at the time of the annual sessions of the Pacific Coast Section of the American Association for the Advancement of Science, until the present year.

The present officers of the organization are: president, Dr. W. A. Clemens, Pacific Biological Station, Nanaimo, B. C.; vice-president, Dr. H. U. Sverdrup, Scripps Institution of Oceanography, La Jolla, California; secretary, Dr. C. L. Utterback, University of Washington, Seattle, Washington.

This organization has excellent potentialities for extending its scope and encouraging oceanographic investigations in the Pacific. However, financial assistance, in addition to the annual dues of one dollar per member, will be needed before it can become an institution as effective as the International Council for the Exploration of the Sea. It should be pointed out that the International Council for the Exploration of the Sea is maintained by contributions from the various countries bordering on the North Atlantic and the Baltic Sea. Furthermore, several officers are permanently employed by the latter organization, whereas all the work of the Oceanographic Society is purely voluntary on the part of certain members who are elected to office. As the work of these officers is in addition to their regular scientific duties, a comparable amount of the time cannot be given to furthering the activities of the Society.

This year, the Oceanographic Society of the Pacific is holding its annual meeting in connection with the Sixth Pacific Science Congress. The Society is taking this opportunity to bring its existence and activities to the attention of the Pacific Science Association and is inviting the scientists of other countries bordering on the Pacific to membership.

PUBLICATIONS ON OCEANOGRAPHY COVERING THE ENTIRE PACIFIC AREA

The Committee at this time desires to call the attention of the Congress to several outstanding publications that are of general interest to all within the Pacific area.

The National Academy of the United States has recently published a monumental work by Dr. T. Wayland Vaughan, entitled, *International Aspects of Oceanography.* In this volume attempts have been made to give a complete outline of all oceanographic institutions and marine stations throughout the world. Information is given relating to the location of the various institutions, their directors, the scope of their research, the nature of their physical plant, and other pertinent matter. The volume also contains articles by various authors who discuss certain important oceanographic investigations. Dr. Vaughan also points out our lack of knowledge of the South Pacific Ocean. He says:

> Knowledge of much of the South Pacific is nonexistent. West of the Galapagos Islands from about Long. 93° W, along and near the Equator to Long. 155° W, there are only a few lines of soundings. South of Lat. 20° S there are many areas five degrees on a side and some ten degrees on a side within which there is not a sounding. Some of these areas approximate 360,000 square nautical miles in dimensions. The South Pacific is the least known of the great oceanic areas.
>
> Finally, it will be suggested that the deficiencies in information on sea-bottom configuration be brought to the attention of the governments of the different countries and that they be requested to help in extending soundings to areas inadequately known. Charts showing the sounded and unsounded areas, brought up to date, should be distributed. It is preferable to have these charts on a projection that extends to the polar regions. The Mercator's projection unfortunately does not do this. Lambert's equal surface projection, utilized by Sir John Murray and the Institut für Meereskunde in Berlin in its publications on entire ocean basins, meets the need. It is suggested that this matter be taken up with the International Hydrographic Bureau to see if it can enlist help in surveying imperfectly known and unknown areas. Attention will be called to the discussion of the subject at the Fourth International Hydrographic Conference in Monaco, April 13–22, 1937, Report of the Proceedings, pp. 121, 340, 405. The International Hydrographic Bureau has already under consideration international coöperation between national hydrographic offices.

Another outstanding volume of general interest that has appeared is the *Geographie des Indischen und Stillen Ozeans,* by Professor Gerhard Schott of the Deutsche See Warte, Hamburg, Germany.

REPORT OF ACTIVITIES OF THE INTERNATIONAL HYDROGRAPHIC BUREAU, MONTE CARLO, MONACO

By M. P. de Vanssay de Blavous

The Bureau has collated all the oceanic soundings carried out in the Pacific Ocean in order to issue a third edition of the General Bathymetric Chart of the Oceans on a scale of 1:10,000,000 at the Equator. At present, Sheet A III (China Seas) is in hand.

The Bureau has grouped the information in connection with the mean sea level for a number of harbors and stations distributed around the Pacific area. This information has been sent to the Secretary of the International Association for Oceanography at the Tidal Institute, Liverpool.

The Bureau has issued historical notes concerning shoals the existence of which is doubtful or approximate, in the various oceans of the world. The notes relating to the Pacific area have been issued in Parts D and E of *Special Publication No. 20* of the International Hydrographic Bureau, dated respectively January, 1933, for the North Pacific Ocean, and July, 1933, for the South Pacific Ocean, with corrections to July 1, 1938

The International Hydrographic Bureau has published a catalogue of original charts concerning the Pacific Ocean (International Hydrographic Bureau's *Special Publication No. 25b.*), Part III (May, 1935).

The Bureau has also published a list of harmonic constants of the tides for a very large number of places in the world, among which are 900 stations approximately in the area of the Pacific Ocean (December, 1936).

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REPORT OF ACTIVITIES OF THE INTERNATIONAL FISHERIES COMMISSION, SEATTLE, WASHINGTON

By W. F. Thompson

Hydrographic conditions and the currents in the waters off the coast of British Columbia and in the Gulf of Alaska are of importance to the International Fisheries Commission, because of their influence upon the early life history of the halibut. Temperature affects the rate of development of the pelagic eggs and larvae; density controls their vertical distribution in the water, and the currents determine their horizontal dispersion from the spawning grounds on which they originate.

The general currents in the Gulf of Alaska were studied by means of temperature and salinity observations along various sections occupied during January of 1927, 1928, and 1929. Publication of the results for 1927 and 1928 was announced at the last Congress. Results for 1929 were published in 1936 as International Fisheries Commission Report No. 10, entitled, "Hydrographic Sections and Calculated Currents in the Gulf of Alaska, 1929," by Thomas G. Thompson, George F. McEwen, and Richard Van Cleve.

Since 1933 the Commission's hydrographic investigations have been carried out in conjunction with quantitative net hauls and have been designed to yield necessary information regarding the factors associated with the development and vertical distribution of the eggs larvae. Temperatures and samples for the determination of salinity and usually of dissolved oxygen were taken at 50-meter intervals from the surface to a depth of 1000 meters, or to the bottom in shallower water.

The number of such hydrographic stations not previously reported, their general location, and the time of year when they were occupied, are as follows: 6 stations off Ocean Cape in January, 1933; 1 station east of Cape St. Elias in December, 1933; 6 stations near Portlock Bank in February, 1934; 4 stations in Dixon Entrance in December, 1934; 7 stations in the neighborhood of Cape St. James between December, 1934, and February, 1935; and in the latter location 19, 13, 14, and 17 stations in January and February of 1936, 1937, and 1938, and between December, 1938, and February, 1939, respectively.

A study of the surface currents by means of drift bottles, announced at the last Congress, was carried on from 1930 to 1935 inclusive, between the coast of Washington and the Alaska Peninsula. Results for the years 1930 to 1934 inclusive have been worked up and were published in 1936 by William F. Thompson and Richard Van Cleve in International Fisheries Commission Report No. 9, entitled, "Life History of the Pacific Halibut. (2) Distribution and Early Life History."

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REPORT OF THE AUSTRALIAN NATIONAL COMMITTEE ON OCEANOGRAPHY

By E. C. Andrews

Report by Professor W. J. Dakin

Professor W. J. Dakin contributes the following important statement of work conducted by himself and his colleagues, together with brief notes on oceanographic work proposed by the newly appointed Commonwealth Fisheries Board.

"Since my last report on oceanographical investigations at Sydney, things have moved ahead very rapidly here. At long last the Government of Australia has instituted a department to investigate the marine fisheries.

"At the beginning of 1938, a small research vessel, the *Warreen*, was launched to aid in work at sea, and already a new marine laboratory is being constructed at Port Hacking, a few miles south of Sydney.

"The University yacht *Thistle* is still in commission, and during the past two years the work at sea has been directed mainly at fishery and plankton investigations. The last physicochemical work carried out at sea indicated a clear cycle in the nitrate and phosphate content of the water on the continental shelf of New South Wales running parallel with the plankton cycle which has again been confirmed. (For earlier reports on these matters see papers in Proc. Linn. Soc. N.S.W., Dakin and Colefax; also LVIII, 1933, and LX, 1935.)

"It is evident that at times the increase in diatoms and other phytoplankton in our coastal waters may, exactly as in the English Channel, lead to severe reduction of the phosphate and nitrate content—in fact, almost to zero. We are not convinced, however, that such changes are responsible for limiting the periods of rich plankton production, and consider that the full story of the seasonal cycle in plankton production requires further elucidation.

"Unfortunately, no work of an oceanographical nature has been continued in our north tropical and subtropical ocean waters.

"Our physicochemical studies during the last two years have been directed, not to the open ocean, but to certain very interesting coastal lakes or lagoons, which are open for long periods to the sea, and then may be closed again for months by sand banks. These salt-water lagoons are great nurseries of fish and Peneid prawns (shrimps in U. S. A.). They abound with life. It seemed likely that the interesting and far-reaching changes in the constitution of the water in these natural experimental laboratories might offer more clear-cut results to investigation than would be forthcoming from our circumscribed efforts to get further out at sea. Regular observation has therefore been made on the salinity, phosphate content, and the nitrate and nitrite nitrogen of one of these areas—Lake Illawarra.

"Reports on these observations will probably be published at an early date.

"Our University work at sea has included an attack on the life history of the Peneid prawn, *Peneus plebejus*. After six years' work a very complete study of this interesting life history has been made. It was published in the Proceedings of the Zoölogical Society of London, July, 1938. Our other work has been an investigation of the seasonal cycle of the macroplankton. A series of interesting captures of individual species has been made which have probably never been taken off the coast since the voyage of the *Challenger*. It is remarkable how not only the position but the dates of capture agree.

"A volume on the plankton of the coastal waters of southeast Australia is now well in hand, and we hope to have this published about the middle of 1939.

"The Commonwealth Fishery Investigations are being carried out under the leadership of Dr. Harold Thompson, D.Sc. (late of Newfoundland), who was appointed to control this division of the Commonwealth Council for Scientific and Industrial Research early in 1938.

"The actual work of the new ship *Warreen* at sea has, of course, only just commenced. The vessel, which has size and lines of a Californian purse-seiner, is being used primarily to explore our seas for pelagic fish with a view to the institution of commercial fisheries. At the same time plankton and hydrographical work is continually being carried out. Water samples are being collected and investigated on a much more extensive scale than was possible before and a full range of analyses is being made. At last there is more probability of a reasonable investigation of the physicochemical conditions prevailing in the southeastern Pacific—at least to a depth of 1000 meters. The Zoölogy Department of the University of Sydney has been collaborating in the analyses of the sea water.

"Dr. Thompson's fisheries work will tend to confine the sphere of action of the ship to the coastal areas, but it is proposed to carry out a repeated series of observations from the latitude of the Tropics down to that of southern Tasmania.

"The following are some particulars of the *Warreen:*

"*Dimensions.* Length over all, 82 feet; beam, 19 feet; draft (mean), 8 feet, 6 inches.

"*Hull.* Steel.

"*Engines.* Main, 215 b.h.p., 4-cycle Diesel.

"*Wireless equipment.* Two transmitters and receivers in one unit, a long-wave for commercial work and a short-wave for communication with aircraft.

"*Depth-recording apparatus.* One echometer of the usual and recording type, capable of measuring down to 350 fathoms.

"*Refrigeration and fish storage.* A small cork-insulated fish hold for use with crushed ice. Also refrigerated cabinets, one below deck and one in the laboratory.

"*Fishing gear.* One Danish seine, one purse seine, 350 yards in circumference and 50 yards deep. One takedown tank for live bait for tuna. Lines of varying kinds, harpoons, and dredges.

"*Laboratory and scientific equipment.* Insulated water bottle. Reversing water bottle. Standard plankton nets. Drift bottles. Apparatus and reagents for analyses of seawater, etc."

ABSTRACT OF INFORMATION FROM SIR DOUGLAS MAWSON

The B.A.N.Z. Antarctic Research Expedition undertaken by Sir Douglas Mawson during the summers of 1929–1931 was that of a well-staffed scientific expedition working between the Ross Sea and Enderby Land. Sir Douglas writes:

"It is not expected that the report will be actually out . . . until April next. It will include an account of the discovery and charting of 800 miles of new coast line. . . . One of the main departments of work undertaken was oceanography, both biological and hydrological. The biological work was conducted under the direction of Professor T. Harvey Johnston of Adelaide University, who, with other officers associated with him, secured material for an exhaustive study of the life of the regions visited."

INFORMATION FROM DR. H. C. RICHARDS

The Great Barrier Reef Committee of Queensland, with Dr. H. C. Richards as chairman, has furnished a report on recent boring operations at Heron Island, from which the accompanying note has been prepared:

Heron Island lies in Long. 151° 57′ E and Lat. 23° 26′ S in the Great Barrier Reef Area, 10 miles from the 100-fathom line and about 44 miles from the Mainland.

The bore was put down during the period May 17–August 13, 1937, in order to gain an understanding of the nature of the reef and its foundations. A previous bore had been put down at Michaelmas Cay in Long. 145° 59′ E and Lat. 16° 36′ S in 1927, about 700 miles to the northwest of the Heron Island bore along the reef. The depth reached was 600 feet. The depth reached in the Heron Island bore was 732 feet.

The logs of the two bores are very similar. "It is difficult," writes Richards, "to believe that it is merely a coincidence that, in each case, loosely coherent coralline material extends to a depth of approximately 450 feet below the surface level, there to be succeeded by noncoralline material, in the nature of loosely coherent quartz sand with abundant foraminifera and littoral shell fragments such as one finds on the existing beaches in these latitudes today." (H. C. Richards, "Problems of the Great Barrier Reef," Univ. of Queensland Papers, Dept. Geol., 1938).

Difficulties encountered in boring have not permitted the gaining of information concerning the thickness of the coral matrix and its physical condition.

Oceanographic Work in Moreton Bay, Queensland, in 1938

Dr. Dorothy Hill reports as follows:

"The first expedition of the Science Students Association of the University of Queensland was organized to make oceanographic investigation in Moreton Bay, the schooner *Cambria* being generously loaned as a movable sea station for the twenty undergraduates and graduates of the party. A fortnight's work was done in January, 1928, studies being undertaken in as many branches as the personnel permitted, so that the possibilities for research in the Bay might be more fully appreciated. Bird and Goat Islands and the shoal (a fringing coral reef) from which they rise formed an admirable unit for detailed work, and topographical, geological, physiographical, botanical, and zoölogical surveys were made and maps prepared. A somewhat wider area was worked for water, bottom sediments, and plankton sampling, most of the chemical analyses being made at a land station at Dunwich.

"The Great Barrier Reef Committee has resumed its investigations in Moreton Bay on the factors limiting coral growth, expeditions being made possible by the generosity of members of the Royal Queensland Yacht Club, who lend yachts at week ends. There are, in the Bay, reef flats and fringing reefs bare at low water, with a 22-species assemblage of dead corals, all of which are found living farther north in the Great Barrier Reef. These reefs shoal gently to 6 or 8 feet below M.L.W., and on many such slopes *Favia speciosa* is the only coral now living; but places are known, such as off Peel Island, and around Bird and Goat Islands, where 14 living coral species, forming a different assemblage from the dead reefs, have been collected. The causes of these changes in the growth of coral in the bay are being sought by studying the action of tidal currents and wind waves, sand movements, and fresh-water floods, and by collecting evidence of change of level. This year's investigations have been made along the south and west of Peel and Green Islands, and the coöperation of the Royal Australian Air Force has been sought in making an aerial photographic survey of these islands and of the tidal delta of the South Passage." (24th Nov., 1938.)

OCEANOGRAPHY IN BRITISH COLUMBIA

By C. McLean Fraser

During the years 1933–1938, the work in oceanography in British Columbia was largely centered in the activities of the Fisheries Research Board of Canada (Biological Board of Canada) at the two main stations, Nanaimo and Prince Rupert, and at the several subsidiary field stations, where these activities were not confined to oceanographic investigation, but several other Government Departments and various other organizations gave valuable coöperation or carried on investigations independently. Those making the greater contributions were: The University of British Columbia, the provincial and federal Fisheries Departments, the National Research Council, the Department of Marine, the Department of Naval Service, the International Fisheries Commission, the Hydrographic Service, the Meteorological Service, the Provincial Department of Public Health, the Provincial Game Commission, and the Canadian Pacific Steamship Service. The Oceanographic Laboratories staff of the University of Washington made several series of observations in British Columbia waters and, in many ways, coöperated in the research of the Northeast Pacific.

The report of the work done in these six years may be divided into four sections, corresponding to the subdivisions made in the work of the Standing Committee on Oceanography (as there are no coral reefs along this part of the coast, the fifth section does not come into consideration), under the headings: Physical and Chemical Oceanography, Fundamental Marine Biology, and Fisheries, and Fisheries Technology. A single investigation may affect two or more of these sections, but, in the main, one section may be considered as paramount for each investigation.

Physical and Chemical Oceanography

The field work in the Strait of Georgia and in the fiords adjacent to it was practically concluded for the time being in 1933, and the examination of the material and data obtained was completed in the following year. Comprehensive reports were prepared and published, dealing with the theory and practice of oceanographic methods as developed in the course of the investigation, and with the physicochemical conditions, the high phosphorus content of these waters receiving special attention. The tendency to stratification in the water of the fiords, especially in those with a definite threshold near the entrance, where there may be an entire lack of oxygen in the lower depths and the water may have a strong odor of hydrogen sulphide, was noted specially.

While this work was being concluded, a start was made on the conditions of the sea off the open coasts. This was begun by taking advantage of the courtesy of the Hydrographic Service, when the facilities of the Survey ship, *William J. Stewart,* were offered and accepted, first as a preliminary, in 1933, and for further work in 1934 and 1935. Many water samples were analyzed for chlorides, dissolved oxygen, silicates, phosphates, and nitrites, and temperature, density, and pH readings were taken. Particular attention was given to tidal and other currents, and hydrodynamic studies were made. The area covered was the coastal waters off Vancouver Island and the Queen Charlotte Islands.

These observations and data served as a good basis for the physicochemical work in these areas, but there was a limit to their application. Without seriously interfering with the regular work of the survey, it was not possible to get water samples and readings at the necessary regular intervals in time and space to make reliable comparisons or to draw reliable conclusions, especially in hydrodynamics. However, in 1934, and in succeeding years, through the courtesy of the Naval Service, H.M.C.S. *Armentieres* was made available for several extended expeditions to make the necessary observations at suitable times and at suitable locations. Sections at right angles to the coast and extending out over the continental shelf for more than 100 miles were observed by taking stations at intervals to obtain various physical and chemical data. These were analyzed and charted, to indicate the currents. These sections extended far enough to cross the inshore area, where drainage is a seasonal factor, to a second area where there is a northerly flowing coastwise current, and reaching into a third area where open-sea conditions exist. Attention has been strongly focused on the area off the southwest coast of Vancouver Island, but the whole area north from this to the northern portion of the Queen Charlotte Islands has been included in the investigation.

To tie up with these data, daily observations of sea-water temperature and salinity, the atmospheric temperature, precipitation, wind force, and direction have been carried on continuously at ten points along the coast, from William Head, to the south end of Vancouver Island, to Langara Island to the northwest of Graham Island, Queen Charlotte Islands.

Taking all these observations into consideration, it has been possible to get a good idea of the way in which the movements of the ocean waters are affected by the three factors, tides, wind currents, and gradient currents. Numerous charts have been worked out to show these effects, and it looks as if it would be possible in time to form a firm basis for a prediction of the physical and chemical conditions in the fishing areas which might be used in fisheries predictions.

The Hydrographic Survey is adding much each year to the information on depths, bottom contours, and so on, in the inshore waters, but the area of these waters in British Columbia is so vast that a year's work, no matter how extensive and intensive it may be when considered by itself, deals with but a small fraction of this area.

The Canadian Pacific Steamships continue to take readings over the various trans-Pacific routes, for the meteorological office in Toronto, where much data have now been accumulated.

Fundamental Marine Biology

Taxonomic work has been continued, particularly in dinoflagellates, hydroids, trematodes, nematodes, acanthocephala, polychaetes, parasitic copepods, euphausids, mysids, pycnogonids, the various classes of mollusks, and marine fishes. Collections from the west coast of Vancouver Island, and from the Queen Charlotte Islands, have provided the most of the new material.

Life-history studies have been, as always, an important feature. Apart from the marine fishes (treated in another section), the pelecypod mollusks, mainly oysters and clams, have received the most attention. The large Japanese oyster, *Ostrea gigas,* has been introduced extensively into this part of the coast, where, from the introduced spat, it lives and grows very well. Natural conditions do not appear to be favorable very often for satisfactory reproduction. Some of the experiments in artificial stimulation to induce spawning have been very encouraging. A greater difficulty seems to be in the setting of the spat, even when plenty of young free-swimming larvae have developed. Even yet, the difference in physicochemical conditions that produces a good set, or a poor one, or none at all, has not been ascertained.

Numerous observations have been made on the spawning, setting, growth, and fattening of the eastern oyster, *O. virginica,* and the native oyster, *O. lurida.*

The necessity for conservation of some of the clams used commercially, especially *Saxidomus* and *Paphia,* has made it desirable to learn much about the life history of each, so that the period of greatest loss may be determined, with the possibility that this loss can be, at least in part, controlled, for it does not necessarily follow that all the danger comes from the drain on the supply of adult clams.

In this oyster and clam investigation it is very necessary to be able to distinguish the free-swimming larvae of these commercially valuable species from one another and from those of other bivalve species that spawn at or near the same time as any of these. Identifying features of several of them have been worked out and recorded.

Several species of crabs have been reared through successive larval stages to the adult condition, and the various stages have been examined and described. These studies are adding much to the information on the relationships existing between various genera and species.

Further investigations have been made on the life history, time of appearance, and time of spawning of the marine wood borers, as well as of several species that are closely associated with them in or on these wooden surfaces.

Miscellaneous investigations have been made on the food of merganser ducks, and other marine fowl, in its economic relations to other species of animals; of the stomach contents of fur seals; on the nervous system of barnacles, with taxonomic reference; and on the function of the crystalline style in clams.

FISHERIES

The Fisheries Research Board has given strong support to Fisheries investigation in British Columbia, both on marine and fresh-water fishes. These will be reported upon only so far as they can be considered oceanographic. The five species upon which the most work has been done, the five species of salmon, offer the greatest difficulty in placement, as they are anadromous. All of them begin and end their lives in the fresh water, but in the long, intervening period in the sea it is difficult to follow their movements, to get much idea of what is happening to them. Some individual spring and coho may spend their sea lives in inner waters, but most of them follow the example of the other three species that linger little inshore on the way out or take little time to loiter on the inward journey. Tagging experiments and scale reading supply most of the real information. During these six years, the sockeye along the whole coast and the pink salmon of the Queen Charlotte Islands have been studied most assiduously.

The halibut has been left entirely to the International Fisheries Commission. The statistical, embryological, and life-history studies have supplied the information that has served as the basis for regulation of the fisheries to bring about an increase in abundance, of the larger fish, at least, especially on the fishing banks adjacent to the Queen Charlotte Islands, where they had been much on the decline.

The herring and pilchard fisheries are also of first-rate importance, and doubt of their ability to stand the magnitude of the fishing strain that has lately been placed upon them has led to the placing of much stress on investigation of these two species. With respect to the herring, this has dealt with analysis of catch records and of random samplings, composition of commercial catches, dominance of individual year classes, racial studies, vertebral counts, plankton studies regarding food content, immigration, and intermingling of stocks, condition at different times of the year, influence of the tide and moon on the size of catches, selectivity of herring drift nets of different mesh, and tagging results. With respect to the pilchard, the types of investigation have been much the same. In coöperation with the California Fish and Game Commission some extended tagging has been done, with the result that strong evidence has been obtained that there is some general movement of the pilchard schools for long distances along the coast.

Less extensive studies have been made on several species of somewhat less economic importance. The life history of the ling cod has been pretty well worked out, but some points still need to be cleared up, and further observations are necessary on the detailed distribution.

Experimental work has been done on the salting of anchovies, and for making use of them in paste, meal, and oil. Vertebral counts on the capelin indicate a sexual dimorphism. The appearance and distribution of eulachon and surf smelts have been studied. The possibility of successful planting of shad has been investigated. The classification and distribution records in the whole field of marine fishes in British Columbia have been brought up to date.

Fisheries Technology

Most of the work in fisheries technology has been done at the Fisheries Experimental Station at Prince Rupert. The research has been so extensive and so varied that it is impossible to give any adequate idea of it in a short summary. Some general statements, with little or no detail, are all that may be attempted.

Among the most important fields of investigation the work on the vitamins A and D assuredly take a place. Methods of assaying vitamin potency that have been developed elsewhere have been used; several of these have been improved and new methods have been developed. These methods have been applied to various fish oils. Pilchard oil provides high potency in both vitamins. The difference in the potency in the oils from the liver and from various other organs and tissues has been worked out in much detail, as well as the variation in the potency in pilchards caught in different localities and at different times of the year. Somewhat the same procedure, but not always in the same detail, has been carried out on the halibut, herring, sockeye, pink and chum salmon, steelhead, gray cod, rock cod, ling cod, black cod or sable fish, and ratfish, as well as on sharks, porpoises, hair seals, sea lions, and sperm whales.

While oils have been the basis for the most of the work on vitamins, they have been used for several other purposes as well. This entailed the chemical analysis of many of the liver and body oils, the determination of the specific gravity, the coefficient of expansion, unsaturated fatty acids, hydrogenation, polymerization, molecular weight, viscosity, refractive index determination of polymerized oils in various solvents, and isomerism—all these in connection with the use of oils for commercial and medical purposes.

Accompanying these determinations there have been more isolated problems of research, such as the nature of pigments in salmon-body oil and in pilchard oil; polymerization to increase the value of marine oils for use in paints, varnishes, and soaps; the purification of fatty acid by-products; the use of fatty acids to produce antiseptics, emulsifying agents, and thermoplastic products; cold clearing; polymerization and hydrogenation of cottonseed oil and pilchard oil; production of oils from livers of low oil content; processing of fish for oil extraction; effect of soap formation *in situ* in oils of high vitamin potency; the nature of the oil in canned sardines; rancidity in fish oils and suitable antioxidants; and stearine pitches for roofing compounds.

In the industry the production of fish meal is commonly associated with the extraction of oil. Work has been done on the preparation and analysis of these fish meals.

Much of the fish oil comes from the liver, but there are other liver values.

Some research was carried out on preparation and assay of the antianaemic factor in various fish and marine mammal livers, on digestion of liver with various enzymes, and on the alkali digestion of liver proteins.

Other subjects of research, depending largely or entirely on chemical analysis, have been autolysis of fish muscle, phosphorus in fish muscle as an index of staleness, texture and freshness of halibut, chemical and biochemical studies of halibut-muscle juice, buffer capacity of fish muscle, rachitogenic diets for rats, copper content of canned abalone, paralytic shellfish poisoning, and the cause of curd in canned salmon.

Bacteriological subjects of research are often associated with chemical analysis. Some of the more distinct subjects have been the rate of spoilage in marine products under various physical and chemical conditions, bacteriological testing with reference to the canning of crabs and clams, indicators of bacterial population in halibut juice, tests for spoilage in halibut, antiseptics in the holds of vessels where fish are carried, and insulation for the ceilings of the holds in fishing vessels.

Cooling and refrigeration.—Some of the problems attacked were cooling and freezing methods; quality in cold storage fish; keeping qualities of halibut in ordinary, benzoic acid, and ionized ice; storage periods in ice; frozen salmon fillets and wrapping in cellophane; the keeping quality of frozen salmon fillets; an attempt to produce a perfect ice glaze; the cause and method of preventing rusting; freezing of shellfish; autolysis in iced fish.

Processing.—In the attack on various problems arising in processing the following were included: Methods involved in preparing smoked fish products—salmon (pink and jack spring), halibut, steelhead, red cod, sablefish, eulachon, smelts; kippered and hard smoked herring; spiced surf smelts; seafood specialty products; the canning of grayfish and sablefish; and the canning of soft shelled clams.

Miscellaneous.—The conditions conducive to dry rot in vessels, and methods of improving these conditions; parasitic protozoan disease of coho salmon; analyses of water obtained from various sources.

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AN OCEANOGRAPHICAL SURVEY OF THE COAST OF CHINA

By H. W. Wu and S. F. Tang

During the period June to November, 1935, a general oceanographical and biological survey of the Gulf of Poi-Hai and of the Coast of Shantung Peninsula was carried out by the National Institute of Zoölogy and Botany, Academia Sinica, Nanking, China.

The territory investigated covered the coastal waters from Tsingtao northward to Ching-Wang-Tao, 36°–39° 45′ N Lat., 118°–123° E Long., and included the Gulf of Poi-Hai and the coast of Shantung Peninsula. In this area thirty-one stations were established. In each month of the period one observation was made at every station. At each station observations were taken from the surface and from every twenty meters below the surface.

The whole survey was carried out on board one of the Chinese Navy gunboats, *Ting-Hai,* 1100 tons displacement, which was built in 1914.

The oceanographical report on that survey has been published in *Sinensia,* Vol. 8, No. 1, February, 1937.

The first part of the report is an introductory note written by Dr. C. C. Wang, Director of the Institute of Zoölogy and Botany, Academia Sinica. The second, with five tables, three graphs, and seven charts, is the report on the physical conditions of the sea water, and the third, with three tables, three graphs, and two charts, is on the chemical side.

In the second part we reported the depths, the specific gravity, and the temperature of the sea water at different depths; also the color, the transparency, and the direction and speed of the current, all of the surface water.

Near the mouth of the Yellow River it was found that the color of the water was No. 13 on Forel's scale and the transparency 0.5 meter. As to temperature, it is of interest to note that in June and July the surface water temperature was generally lower than the air temperature, whereas in August, September, and October the reverse was the fact.

A system of complete closed isotherms was found in the Gulf of Poi-Hai. In this gulf the direction of rotation of the currents was counterclockwise.

In the third part, the chlorinity, pH value, and silicon content of the sea water were reported. The chlorinity at stations throughout the survey varied from 12.26 per cent to 17.94 per cent. The lowest value was in the Gulf of Poi-Hai and the highest was along the Shantung Peninsula. During these five months the chlorinity of the surface water at all stations also varied from time to time; the highest, 17.13 per cent, was in June, and the lowest, 16.31 per cent, was in August. The chlorinity increased with the depth of the sea about 0.3 per cent for every twenty meters from the surface downwards. As to the pH value, the determination was carried out only in September and October. It varied from 7.93 to 8.14 at the surface and from 7.93 to 8.18 at the depth of twenty meters. Like the chlorinity, it increased toward the bottom of the sea. The silicon content was also studied in the month of October. It varied from 0.001 to 0.002 milligram-atoms per kilogram of sea water.

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OCÉANOGRAPHIE PHYSIQUE DE L'ATLANTIQUE SUD ET DU PACIFIQUE: CARACTÈRES COMPARÉS

Par Camille Vallaux

Comme science munie de moyens d'investigations adéquats, l'océanographie physique date d'un siècle à peu près. Les recherches de son premier demi-siècle ont fait ressortir surtout de nombreuses analogies entre les grands Océans (voir par exemple J. Y. Buchanan, "On Similarities in the Physical Geography of the Great Oceans," *Proc. Roy. Geog. Soc.*, 1886). De ces analogies, ou homologies, on faisait volontiers des identités. Mais les progrès nouveaux accomplis depuis trente ans (1° en raison de nombreuses explorations nouvelles, 2° à l'aide de nouveaux instruments d'observations plus précis) font ressortir des différences croissantes de comportement, statique ou dynamique, entre les diverses parties de la mer planétaire (mers du large, les mers secondaires exclues). On peut déja préciser de nombreuses différences entre l'Atlantique, assez bien exploré, et le Pacifique, où l'exploration progresse tous les jours. Il serait moins commode de le faire pour l'Océan Indien et pour l'Océan Austral, où nos connaissances demeurent fort en arrière.

Les différences se groupent sous les principaux chefs ci-après:

1° *Morphologie et Formation:* Depuis Suess nous connaissons les côtes *de type atlantique* et les côtes de *type pacifique*. Mais ce ne sont pas seulement les côtes, c'est l'allure générale de la topographie sous-marine qui montre des diversités notables. Fosses étroites et profondes avec maximum de profondeur le long de toutes les côtes continentales et insulaires de type pacifique (sauf celles de l'Amérique du nord). Le même caractère ne se présente dans l'Atlantique qu'en lisière de l'arc des Antilles (et aussi le long des Antilles australes, si l'on comprend cette région dans l'Atlantique). La convexité générale du sol sous-marin est donc un peu plus accusée dans le Pacifique. Pour l'un comme pour l'autre océan les sondages acoustiques révèlent un nombre croissant d'accidents du fond. On peut se hasarder à dire que ces accidents, *au large,* paraissent moins accentués et moins nombreux dans le Pacifique, où en revanche la profondeur moyenne serait plus grande. Au point de vue de l'histoire et de la formation, les géologues, qu'ils soient ou non partisans de la théorie de Wegener, s'accordent à voir dans l'Atlantique un Océan de formation plus récente, et dans le pacifique un élément fort ancien de l'histoire du globe; il en est ainsi même chez ceux qui admettent un ancien continent ou un vaste archipel intrapacifique des Hawaii à l'Île de Pâques. On peut rappeler, par curiosité, l'hypothèse cosmogonique de H. C. Darwin qui fait de la lune un morceau autrefois détaché de la scorie superficielle terrestre; ce morceau aurait occupé la place aujourd'hui recouverte par les eaux du Pacifique.

2° *Composition du sol sous-marin:* Renseignements encore insuffisants pour les deux océans. Toutefois, la plus grande profondeur moyenne du Pacifique paraît en rapport, pour les sédiments abyssaux, avec la place plus grande occupée dans cet Océan par l'argile grise et rouge et par le terme de transition vers cette argile, la vase à radiolaire (voir la carte dans O. Krummel, *Handbuch der Ozeanographie,* I, 193). L'Océan Atlantique est essentiellement le domaine de la vase calcaire à globigérines. Dans le Pacifique dominent les dépôts silicieux.

3° *Structure physique et chimique des eaux marines:* Trois points de différence paraissent ressortir aujourd'hui: 1° Si les répartitions thermiques en surface, commandées par les climats sont à peu près les mêmes dans les deux océans, en profondeur les couches tièdes ont dans l'Atlantique, et surtout dans l'atlantique nord, une extension incontestablement plus grande. L'Atlantique nord, par rapport à l'Atlantique sud et surtout au Pacifique, est l'océan des eaux tièdes. 2° Le rapprochement des nombreuses mesures aujourd'hui acquises indique pour tout le Pacifique, en surface et en profondeur, une salinité inférieure à celle de l'Atlantique. Si le chiffre 35 à 36% exprime assez exactement la salinité de l'Atlantique, le chiffre 34 à 35 exprime celle du Pacifique; chose d'autant plus remarquable que l'Atlantique reçoit une quantité d'eaux douces beaucoup plus grande; par là on voit combien peu compte l'eau de ruissellement dans la structure chimique de la mer planétaire. 3° Les mesures encore trop rares de l'indice d'oxigénation paraissent attester qu'il y a en profondeur, dans le Pacifique, des eaux moins ventilées que dans l'Atlantique et soustraites depuis bien longtemps à toute communication avec la surfase.

4° *Glaciation:* L'Atlantique, Océan tiéde, est pourtant celui où les glaces de terre et de mers s'approchent le plus de l'équator. Dans le Pacifique, Océan moins tiède, elles en approchent beaucoup moins. Autre contraste que la morphologie explique, mais en partie seulement. Dans l'hémisphère nord; l'Atlantique est largement ouvert sur les mers du pôle; les glaces marines descendent jusqu'au 45°, les icebergs jusqu'au 41°; le Pacifique nord, à peu près séparé des mers du pôle, n'a point d'icebergs, mais seulement des glaces de banquettes et des glaces flottantes formées surtout dans la mer d'Okhostk, à laquelle les océanographes allemands donnent du reste une place trop grande. Dans l'hémisphère sud, les icebergs approchent parfois de la pointe méridionale de l'Afrique (35° lat. Sud); ils n'approchent même pas du Cap Horn, qui est au 55° lat. Sud; leur limite remonte plus au nord à travers le Pacifique, mais sur ce point nos renseignements ne sont pas assez nombreux.

5° *Circulation de surface et de profondeur:* On peut maintenant affirmer qu'à ce point de vue, d'une manière générale, les homologies autrefois reconnues par Buchanan se changent en diversités extrèmement nettes, que l'on peut résumer ainsi: les courants de surface et de profondeur du Pacifique sont moins rapides et moins nettement déterminés que ceux de l'Atlantique; parmi les courants de surface du pacifique, il n'y en a presque aucun qui appartienne à la catégorie des "*streams*"; ce sont tous des "*drifts*"; en profondeur, les directions relevées dans le Pacifique sont souvent fort incertaines, ou tellement lentes que les indices, observés avec une extrême précision, suffisent à peine à les déceler. Ainsi, l'ancienne homologie si longtemps établie et si obstinément maintenue entre le courant de l'Atlantique nord (courant de Floride et Gulf Stream) et le courant du Japon (Kuru-Shio) n'a réellement aucune raison d'être: elle a été détruite par les récents travaux de l'océanographie américaine (recherches de *l'Atlantis*) et par les travaux de l'hydrographie japonaise. Il est fort probable qu'il faudra également renoncer à l'homologie entre le courant du Benguela et le courant du Pérou (courant de Humboldt) : car, si le courant de Benguela a été à peu près confirmé dans son ancienne structure par les travaux du *Météor*, le courant du Pérou a pris, depuis les travaux du *Discovery II* une physionomie toute nouvelle qui interdit de faire de lui un simple segment de la giration sud-pacifique. Il faut remarquer de plus que, dans l'Atlantique, le dessin des côtes et l'étranglement de l'océan sur l'équateur rejettent dans l'hémisphère nord la plus grande partie des eaux chaudes équatoriales, ce qui est evidemment en rapport avec la masse d'eaux tièdes que présente l'Atlantique nord en surface et en profondeur. Rien de pareil dans l'Océan Pacifique.

GUATEMALA

In response to a letter sent to the Republic of Guatemala, the chairman of the committee received an acknowledgment from the Licenciado J. Antonio Villacorta C., Secretario de Estado en el Despacho de Educación Pública, who forwarded a bathymetric chart of the Guatemalan coast. This chart had been prepared by the Director General of Obras Públicas.

As far as could be ascertained, no physical, chemical, or biological work in oceanography was being carried on by any Guatemalan institution.

TRAVAUX DE L'INSTITUT OCÉANOGRAPHIQUE DE L'INDOCHINE

Par M. P. Chevey

Cet institut, créé en 1930, est installé à Cauda, près de Nhatrang (Annam). Il a à sa disposition un navire de 750 tonnes, le *De Lanessan,* et il exécute des croisières regulières dans les mers qui baignent la péninsule indochinoise.

Les résultats de ces croisières sont publiés dans les *Annales de l'Institut Océanographique de l'Indochine* (six volumes parus à l'heure actuelle).

Une note du directeur actuel de l'Institut, M. P. Chevey, sur l'ensemble des travaux accomplis au cours des dernières années sera présenté au Pacific Science Congress.

Institut Océanographique, Paris. J. ROUCH

Hydrographie Générale

(Reconnaissances hydrographiques et océanographiques, et recherches de géophysique, exécutées dans l'Océan Pacifique et la mer de Chine méridionale par les missions hydrographiques et par les bâtiments français de guerre et de commerce.)

TRAVAUX SUR LE TERRAIN

Indochine française: Les levés réguliers commencés dans cette colonie en 1905 et interrompus pendant près de 8 ans à partir d'août 1914 ont été repris en avril 1922. Ils ne sont pas encore terminés et sont continués sans interruption. Le levé des côtes du Tonkin et d'une importante partie du Golfe de ce nom est achevé. En Annam il ne reste plus à reconnaître que 100 milles de côte. Le levé du Golfe du Siam a été commencé en 1934. En Cochinchine et au Cambodge les sondes ont été étendues à une centaine de milles des côtes et de nombreux plateaux coralliens couverts de 8 à 9 mètres d'eau ont été découverts à une cinquantaine de milles à l'Est du Cap Saint Jacques. Dans quelques années, l'hydrographie de l'Indochine française sera achevée.

Des sondages bathymétriques ont été effectués jusqu'à l'isobathe de 1500 mètres, au large du Cap Padaran sur l'emplacement d'un banc d'existence douteuse (Capricieuse) qui n'a pas été retrouvé. Aux abords des récifs des Paracels, sur lesquels l'Indochine a construit un phare, des sondages acoustiques ont décelé un relief sous-marin des plus tourmentés.

Quelques mesures de densité et de température, en surface, ont été prises le long des côtes de la colonie.

Nouvelle Calédonie et dépendances—Nouvelles Hébrides: Des levés hydrographiques réguliers se poursuivent depuis 1935 aux abords de Nouméa, dans la région des centres miniers de Paagoumène, Tangadiou et dans le port de Goro, à l'entree du Canal de la Havannah.

Les abords du récif extérieur ont été sondés jusqu'aux profondeurs de 1500 mètres au Sud de Nouméa. La pente du talus est de 12° en moyenne dans cette région. La fosse des Nouvelles Hébrides a été reconnue, par profils espacés de 20 milles. Diverses lignes de sondages ont été effectuées entre la Nouvelle Calédonie, les Loyauté, les Nouvelles Hébrides. Un banc de 350 mètres entouré de profondeurs de 1000 mètres a été trouvé entre Erromango et Efate. Ces divers sondages bathymétriques ont été effectués avec le système du sondage par détonation (fusil et pétard).

Etablissements français d'Océanie: Des reconnaissances rapides et de peu d'étendue ont été poursuivies dans quelques uns des atolls des Tuamotu. La carte de la rade de Papeete a été levée en détail à grande échelle.

Des sondes bathymétriques ont été obtenues par sondage acoustique (sondage par détonation) dans les groupes: Iles de la Société, Tuamotu, Marquises et entre ces groupes. Les pentes sous-marines des atolls sont considérables et dépassent 30° autour de Fakarava, entre le récif et l'isobathe de 1000 mètres. A signaler une sonde de 300 mètres (Banc du Rigault de Genouilly) entouré de profondeurs de 4000 mètres à 180 milles dans le S.W. de Tahiti.

Ilôt Clipperton: Une carte de cet îlot a été établie par photos aériennes et publiée (n° 5825). Des sondages exécutés par le croiseur *Jeanne d'Arc* autour de cet îlot, pendant les opérations de prise de vues et de triangulation à terre, ont donné une partie de l'isobathe de 500 mètres et ont décelé des pentes de 40% (22°).

Sondages bathymétriques dans l'Océan Pacifique: En plus des sondes bathymétriques dont il a été question dans les paragraphes précédents, des sondages nombreux ont été obtenus par grandes profondeurs au cours des déplacements des avisos coloniaux entre l'Australie, la Nouvelle Zélande, la Nouvelle Calédonie et les Etablissements français de l'Océanie. Quelques sommets d'un certain intérêt ont été trouvées. Ces sommets inconnus jusqu'ici, comme ceux qui ont été trouvés aux Nouvelles Hébrides, dans le S.W. de Tahiti et dans les Marquises et dont il a été question précédemment, feront l'objet, avant d'être définitivement portés sur les cartes, de nouvelles reconnaissances.

PUBLICATIONS DE CARTES, ÉTUDES RÉTROSPECTIVES, MÉMOIRES

Cartographie: Le Pacifique est figuré dans le portefeuille hydrographique français par 3 feuilles (5356, 5361, 5366) a l'échelle de 7 millimètres pour 1° de longitude, soit au 1/15000000 environ. Ces feuilles ont été mises à jour des nombreuses sondes bathymétriques publiées depuis quelques années et rééditées en 1937 et 1938.

La nouvelle édition de la carte 2^B du planisphere 2^A 2^B 2^C, a l'échelle de 5 millimètres pour 1° de longitude sera bientôt achevée. La carte 2^B, completée au point de vue des sondes, donne une vue d'ensemble de l'Océan Pacifique, de la côte de Chine jusqu'au méridien de l'Île de Pâques.

Etudes rétrospectives: Des mémoires manuscrits, se trouvant à la Bibliothèque ou au Archives du Service Hydrographique, étudient la déviation de la verticale à Tahiti. Comme il semble qu'aucune étude de détail de cette anomalie n'ait été publiée, une note résumant ces divers mémoires a été établie pour exposer les résultats obtenus.

Un panneau donnant les itinéraires de 17 voyages d'explorateurs français accomplis dans l'Océan Pacifique de 1766 à 1840 a été présenté à l'Exposition internationale de Paris en 1937. Une réproduction photographique de ce panneau figure parmi les documents réunis par le Service Hydrographique pour le "Pacific Science Congress" de San Francisco.

Mémoires imprimés: Bien que les deux mémoires suivants aient été imprimés antérieurement à 1933, il paraît necessaire de les signaler ici par suite de leur intérêt pour la connaissance du Pacifique et parce qu'ils ont pour auteur le savant hydrographe et océanographe français Pierre Marti prématurément enlevé à la science à la fin de 1938 :

Exploration de la région volcanique sous-marine des îles Catwick. 1929. (Revue Hydrographique 1930. Vol. VII. I. p. 76).

Mission Hydrographique de l'Indochine (juin 1928–mai 1929). Rapport. (Annales Hydrographiques de 1933).

L'INSTITUT OCÉANOGRAPHIQUE DE L'INDOCHINE

Personnel: Le Dr. Chevey a été nommé Directeur titulaire le 30 juillet 1935. Le Dr. Dawydoff est rentré en France et ne fait plus partie du personnel de l'Institut. Deux nouveaux Assistant zoologistes ont été nommés: M. Serène en 1934 et M. Durand en 1938. Un Assistant chimiste doit être nommé en 1939. On doit aussi compter comme collaborateur pour l'océanographie, le Capitaine Dauguet, Commandant le *De Lanessan,* chalutier-laboratoire de l'Institut. Enfin il a été adjoint au personnel de l'Institut un spécialiste chargé des questions économiques, M. Le Poulain, et un Secrétaire-Conservateur du Musée et l'Aquarium, M. Buinguon-Khanh.

Instruments de travail: Il a été installé, depuis le dernier Congrès, un Aquarium marin comprenant 23 Aquariums fixes de diverses tailles (dont le plus grand contenant 20 tonnes d'eau de mer), un bassin à eau de mer courante, un diorama de récifs coralliens présenté sous une lame d'eau de mer courante. Des branchements appropriés conduisent l'eau de mer dans les laboratoires. Le *De Lanessan* n'a pu être utilisé que 3 mois par an en 1934 et en 1935, pour l'océanographie, les difficultés financières nous ayant obligé à le louer à l'Administration des Douanes le reste du temps. Il a été possible de récupérer entièrement le bateau en 1936. De septembre 1936 à janvier 1938, il a stationné au Cambodge comme laboratoire flottant pour l'étude des eaux douces. En 1938, il a été utilisé à diverses reprises par le Gouvernement de l'Indochine, en missions spéciales. Enfin, à l'heure actuelle, il est permis d'espérer qu'il pourra reprendre ses travaux océanographiques, limités au Sud-Annam, depuis 1936. Ajoutons qu'il est actuellement en projet de construire au Cambodge une Station Limnologique, dont les laboratoires seront consacrés à l'étude des lacs et des fleuves rattachés au système du Bas Mékong.

Océanographie physique: Etude des courants marins du Sud Annam, montrant que la pêche dans cette région est sous la dépendance d'une lame d'eaux, relativement froides, qui envahit, certaines années, le plateau continental. En ce cas, la pêche est mauvaise.

Etude des salinités, montrant 3 types d'eaux, sur la côte d'Annam :

1° Eaux deltaïques, $S < 32‰$

2° Eaux cotières, $S = 32$ à $33‰$

3° Eaux du large, $S > 33‰$

Etude comparée du Golfe du Tonkin et du Golfe de Siam, le premier très hétérogène au point de vue températures et salinités, le 2° au contraire, remarquablement homogène (eaux chaudes et dessalées).

Observations régulières en baie de Nhatrang (étude thermométrique, halométrique et marégraphique).

Centralisation d'observations halothermométriques de surface effectuées par des navires des marines de guerre et de commerce.

Océanographie biologique: Récoltes hebdomadaires de plancton de jour et de nuit, à la Station de Cauda, récoltes occasionnelles en mer avec le *De Lanessan.* Triage et envois aux spécialistes.

Etude du cycle marégraphique de 18 ans 2/3 en liaison avec la croissance de certains coraux. Etude du développement de certains coraux.

Faunistique: Caractères nordiques des poissons pêchés à plus de 100 m. de fond, en Annam (faune sino-japonaise) par opposition aux caractères méridionaux des poissons de surface (faune malaise). Etude de la faune des eaux douces du Tonkin, de l'Annam, de la Cochinchine et due Cambodge.

Etude de quelques animaux rares: *Kogia breviceps, Rhineodon typus, Calliscyllium venustum.*

Pêches et Industrie de la mer: La carte des fonds de pêche, éditée en 1930, a été completée par l'adjonction de fonds nouvellement reconnus et des principales zones de pêche indigène.

Une enquête a été entreprise sur les pêcheries cambodgiennes, les époques de ponte des Poissons, etc. . . . pour permettre au Gouvernement de remanier la reglementation actuelle insuffisante.

Une enquête analogue a été entreprise au Tonkin, sur les Mollusques producteurs de nacre et leurs périodes de reproduction ; elle est destinée également à permettre d'établir une réglementation à base scientifique.

L'Institut Océanographique est chargé, depuis 1937, du Contrôle sanitaire ostréicole en Annam : classement des gisements naturels, surveillance des parcs et dépôts, délivrances des Certificats d'origine salubre.

En ce qui concerne les applications industrielles, des essais ont été pratiqués avec succès, à Saigon, sur l'emploi des huiles de poissons comme combustibles dans les moteurs Diesel : le démarrage peut se faire directement à l'huile de poisson, la vitesse et la puissance restant normales et constantes.

Enfin, signalons les essais d'alimentation de bétail et de volaille avec adjonction d'huile de foie de requin. La tolérance est parfaite, à condition de ne pas forcer les doses et le développement parait vivement influencé.

Liste des Travaux Publiés depuis 1934

PUBLIÉS PAR L'INSTITUT

Note n° 21. P. Chevey. Rapport sur le contionnement de l'Institut Océanographique de l'Indochine pendant l'année 1931–1932.
Note n° 22. P. Chevey. Rapport sur le contionnement de l'Institut Océanographique de l'Indochine pendant l'année 1932–1933.
Note n° 23. T. Monod. Isopodes des campagnes du *De Lanessan*.
Note n° 24. P. Chevey. Rapport sur le contionnement de l'Institut Océanographique de l'Indochine pendant l'année 1933–1934.
Note n° 25. R. Bourret. Les Serpents marins de l'Indochine française.
Note n° 26. P. Chevey et P. Carton. Les courants de Mer de Chine méridionale et leurs rapports avec le climat de l'Indochine.
Note n° 27. P. Chevey. Rapport sur le fonctionnement de l'Institut Océanographique de l'Indochine pendant l'année 1934–1935.
Note n° 28. P. Chevey. Echouage d'un Requin-Baleine *Rhineodon* typus, en Cochinchine. Résumé de nos connaissances sur ce poisson.
Note n° 29. Contribution de l'Institut Océanographique de l'Indochine aux travaux du 5 Congrès scientifique du Pacifique, Vancouver 1933.
Note n° 30. R. Serène. Inventaire des invertébrés marins de l'Indochine, 1^{e} liste.
Note n° 31. Hommages à Louis Boutan par M. P. Chevey, A. Krempf, L. Pohl.
Note n° 32. R. Serène. Rapport sur le contionnement de l'Institut Océanographique de l'Indochine pendant l'année 1935–1936. (Epuisé.)
Note n° 33. Lemasson et Chevey. Contribution à l'étude de Poissons des eaux douces tonkinoises.
Note n° 34. P. Chevey. Rapport sur le contionnement de l'Institut Océanographique de l'Indochine pendant l'année 1936–1937 (préparé par R. Serène).
Carte des fonds et zones de pêche des côtes indochinoises.

PARUS DANS DIVERS PÉRIODIQUES

Chevey, P.
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1935*c*. Sur la présence du genre *Anguilla* en Indochine française. C. R. Ac. Sc., séance du 23 decembre 1935.
1936*a*. Sur la présence du genre *Anguilla* en Indochine française. (Bull. Muséum de Paris, 2^{e} série, T. VIII, N° 1.
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1936*d*. (En collaboration avec Dr. J. Pellegrin) Poissons nouveaux ou rares du Tonkin et de l'Annam. Bull. S. Z. F., T. LXI, p. 375.
1936*e*. Les campagnes océanographiques du *De Lanessan* dans la Mer de Chine Méridionale. Revue Scientifique, 75^{-me} année, N° 7, pp. 248–254, 8 figs.
1937*a*. Répartition des températures et des salinités dans la Mer de Chine Méridionale. Assn. Oc. Phys., Procès-verbaux, N° 2, pp. 119–120.
1937*b*. Observation inédite sur un animal marin de grande taille observé sur la côte est d'Australie en 1925. Bull. S. Z. F., T. LXII, p. 294.

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1934. Inscription marégraphique des cycles de rétrogradation des nœuds de la lune par certains coraux constructeurs de récifs. C. R. Ac. Sc., T. 198, N° 19, p. 1708, séance du 7 mai 1934.

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1934. Poissons de la Région d'Hanoi. Bull. S. Z. F., T. LIX, p. 334.

PELLEGRIN et CHEVEY

1934*a*. Poissons de Nghia-Lo (Tonkin). Description de 4 espèces nouvelles. Bull. S. Z. F., T. LIX, p. 337.

1934*b*. Addendum à la note précédente. *Ibid.*, p. 467.

1935. Poisson nouveau du Tonkin appartenant au genre *Sinogastromyzon*. Bull. S. Z. F., T. LX, p. 232.

1936. Cyprinides nouveaux du Tonkin. Bull. S. Z. F., T. LXI, p. 18.

F. LE POULAIN

1938. Le Prahoc. Bull. Economique de l'Indochine, Fasc. 2, p. 329.

R. SERÈNE

1937. Notes sur la biologie et la ponte d'un Silicoderme d'Indochine. Bull. S. Z. F., T. LXII, p. 463.

1938. Note sur l'appareil réproducteur de *Peronia Peronii* Cuvier. Bull. S. Z. F., T. LXIII, p. 87.

1932. Sur un échouage de *Kogia breviceps* à proximité de l'Institut Océanographique de Nhatrang (Annam). Bull. Muséum de Paris, 2ᵉ série, T. IV, N° 4.

REPORT OF THE NATIONAL COMMITTEE OF JAPAN ON THE OCEANOGRAPHY OF THE PACIFIC

DR. HISAKATSU YABE, chairman of the National Committee of Japan on the Oceanography of the Pacific, requested Dr. Mititaka Uda and Dr. Koji Hidaka to prepare reports dealing with the hydrography of the adjacent seas of Japan and a summary of Japanese contribution to theoretical oceanography. These reports follow.

Dr. Yabe summarizes the investigations in chemical oceanography as follows:

Special works in chemical oceanography not mentioned in the reports of Dr. Uda and Dr. Hidaka are those concerning chemical analyses of the deep-sea deposits of the southwestern part of the North Pacific Ocean. Briefly, studies along this line have been carried out in the chemical laboratory of Professor K. Kimura of the Tokyo Imperial University, by H. Hamaguti on radium content and chemical constituents, and by S. Koana on barium-chromium and molybdenum content. Both Hamaguti and Koana used the same samples, which were procured from depths ranging between 1444 and 1654 meters. Of the 14 samples studied by them, 12 consisted of red clay and 2 of Globigerina ooze. All were used for analysis of radium content, and 6 were used for barium-chromium and molybdenum content and chemical constituents. On the other hand, S. Syôzi of the Institute of Geology and Paleontology, Tôhoku Imperial University, carried out chemical analyses relating to the calcium carbonate content on 310 samples collected from the same area as that studied by Hamaguti and Koana. The reports of these works have been published as follows:

H. HAMAGUTI
1938*a*. Radium content of deep-sea deposits. No. 1. Jour. Chem. Soc. Japan, Vol. LIX, No. 2, 1938. (In Japanese.)
1938*b*. Chemical constitution of deep-sea deposits. No. 1. *Ibid.*, Vol. LIX, No. 5, 1938. (In Japanese.)

S. KOANA
1938. Vanadium-chromium and molybdenum contents in deep-sea deposits. No. 1. *Ibid.*, Vol. LIX, No. 11, 1938. (In Japanese.)

S. SYOZI
1938. A study of the deep-sea deposits from the southwestern part of the North Pacific. Contributions from the Institute of Geology and Paleontology, Tohoku Imperial University, in the Japanese Language, No. XXIX, 1938.

A SKETCH OF THE RECENT DEVELOPMENT OF HYDROGRAPHICAL RESEARCHES IN THE SEAS ADJACENT TO JAPAN

By Mititaka Uda

The development of oceanic research in this country since the beginning of the era of Meizi has progressed rapidly, and progress during the last ten years has been astonishing. Large-scale surveys of waters surrounding Japan have been conducted by modern methods, with notable accuracy. At present, both theoretical and experimental studies are in active progress.

The following report outlines the results obtained by many oceanographers in Japan since 1933 in the field of hydrography, and the observations and experiments undertaken in the seas adjacent to Japan.

Bibliographical abbreviations used are the following:

A. R. H. O. Tyosen—	Annual Report of Oceanographical Investigation, published by the Fisheries Experimental Station of the Government-General of Tyosen
B. H. D.—	Bulletin of the Hydrographic Department
B. J. S. Sc. F.—	Bulletin of the Japanese Society of Scientific Fisheries
Geophys. Mag.—	Geophysical Magazine, published by the Central Meteorological Observatory
J. I. F. E. S.—	Journal of the Imperial Fisheries Experimental Station, Tokyo
J. I. F. I.—	Journal of the Imperial Fisheries Institute, Tokyo
J. J. A. G.—	Japanese Journal of Astronomy and Geophysics
J. O. Kobe—	Journal of Oceanography, published by the Marine Observatory, Kobe.
K. K. I.—	Kaiyo Kisyokai Iho, published by the Imperial Marine Observatory, Kobe
K. S.—	Kisyo Syusi, published by the Dai Nihon Kisyo Gakkwai
Mem. Mar. Obs.—	Memoir of the Imperial Marine Observatory
R. O. W. J.—	Records of Oceanographical Works in Japan
S. A. O. I.—	Semiannual Oceanographical Investigation, published by the Imperial Fisheries Experimental Station, Tokyo
Sc. R. T. B. D.—	Science Report of the Tokyo Bunrika Daigaku
S. T. H.—	Suisan Tyosa Hokoku, published by the Hokkaidô Fisheries Experimental Station
S. Y.—	Suiro Yoho (Hydrographical Bulletin), published by Hydrographic Department
T. Z.—	Tigaku Zassi
U. S.—	Umi to Sora, published by Kaiyo Gakkwai, Kobe, in the Imperial Marine Observatory, Kobe.

Instruments and Methods of Observation

In 1936 the Imperial Marine Observatory in Kobe issued "Kaiyo Kansoku Ho (Methods of Marine Observation)," edited by K. Hidaka, Y. Matsudaira, and others, which illustrates and describes standard observations and affords many conveniences to the oceanographer in order to promote the accuracy of oceanographical observations in Japan.

Water bottle.—For the subsurface observation prior to 1926, Kitahara's water bottle, which is an improved type of Petterson's water bottle, was in popular use.

In the era of Syowa, the principal surveying vessels in Japan adopted the reversing water bottles in serial connection (mainly of Nansen's type and sometimes of Ekman's type), with reversing thermometers, which resulted in remarkable accuracy of observation. An experimental comparison of the function and accuracy of Kitahara's and Nansen's water bottles, in particular with respect to leakage of sea water and heat insulation, was made by Z. Yasui, M. Uda, and others.[1]

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[1] Z. Yasui, U. S., 13, 8, 1933; K. Suda, Kaiyokagaku, p. 67, 1933; M. Uda, G. Okamoto, N. Watanabe, U. S., 14, 7, 1934.

Thermometer.—The older observation of water temperature by the ordinary thermometer with official certification, attached to Kitahara's water bottle, was accurate to about 0.1° C. At present, the water temperature is measured at the sea surface by the Fuss rod thermometer of 0.1° C. graduation with official certification, and at subsurface depths by the reversing thermometer, mainly of the Richter and Wiese pattern but sometimes of the Negretti and Zambra pattern, of accuracy to 0.01° or 0.02° C., certified by P. T. R. and N. P. L., respectively. Accordingly, the accuracy of the measurement of water temperature is now ten times higher than before. Correction for secular change of the zero point of the reversing thermometer is sometimes made by repetition of the experiment.

The formula for correction of the reading of the protected reversing thermometer introduced by K. Hidaka,[2] $dt = \frac{(V\ \ T)(T—t)}{1—(V\ \ T—t)}$, has been adopted generally throughout the world, because of its simplicity and rigorousness. The practical method of correction by Hidaka's formula follows the procedure invented by O. Sund which shows the computed value of total correction in a graph. From the experiments by Z. Yasui,[3] the interval required to immerse the reversing thermometer in the water at the depth in question in order to eliminate the inertia of the thermometer is found to attain in six minutes an accuracy of 0.01° C. in the laboratory and, from the experiments by M. Uda and his collaborators,[4] commonly in five minutes in the actual ocean. Z. Yasui has also investigated the personal error for the reading of water temperature.[5]

The use of self-registering instruments in ocean research has gradually increased, as for example in the measurements in the sea, of water temperature, salinity, and currents. At present the self-registering thermometer of the Negretti-Zambra pattern is used successfully in various ways, and it is noteworthy that several fishing boats use such an instrument when searching for favorable localities for catching bonito, because the shoals of bonito accumulate densely around the zone of favorable water temperature in the vicinity of "Siome," at which the water temperature varies abruptly from one side to another. This instrument was utilized by T. Kumada[6] in the water near a keddle net in order to predict the catch of yellowtail. Recently, N. Inoue[7] has investigated the short-period variation of water temperature near a sardine-fishing ground by means of a newly designed electric resistance thermometer.

Salinity and specific gravity.—The measurement of salinity is indispensable for the computation of the density of sea water and for dynamic studies in the ocean. Salinity is measured by Mohr's chlorine titration method, using Knudsen's normal water supplied from the Hydrographical Laboratory in Copenhagen, with Knudsen's burette and pipette. For accuracy, the method of double titration is adopted. A nomograph proposed by N. Watanabe[8] is convenient, in the treatment of abundant samples, for the speedy computation of S from the initial value of titration with the necessary accuracy of 0.01 per cent. Recently M. Okada and T. Ogawa described a new modification of Knudsen's method and constructed a new set of titration tables.[9]

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[2] K. Hidaka, Mem. Mar. Obs., 5, 1, 1932.

[3] Z. Yasui, U. S., 13, 8, 1933.

[4] M. Uda, G. Okamoto, N. Watanabe, U. S., 14, 7, 1934.

[5] Z. Yasui, U. S., 13, 8, 1933; 14, 12, 1934.

[6] T. Kumada, U. S., 6, 1, 1926.

[7] N. Inoue, B. J. S. Sc. F., 7, 4, 1938.

[8] N. Watanabe, B. J. S. Sc. F., 7, 2, 1938.

[9] M. Okada, T. Ogawa, B. J. S. Sc. F., 7, 5, 1938.

There are still many research vessels which use Akanuma's hydrometer (a pycnometer resembling the Kiel pattern and convenient for finding quickly the approximate order of salinity) auxiliarily, and they show the salinity obtained from a reduction value of C_{15} (specific gravity at 15° C.). Before 1926 the hydrometer had been popularly accepted as a comparatively important instrument for the determination of density, and even the value of S obtained by the chlorine titration method has been represented by the corresponding value of C_{15}. As a result of experiments by K. Suda,[10] M. Uda and T. Yamasita, K. Nisida, and Z. Nakai, carried out independently over a period of years, there have been brought to light some sources of error in the hydrometry, such as variation of the surface tension owing to variable conditions of the glass surface or to contamination of the water surface by dust, etc., or by convection in the water specimen, etc., so that at length the accuracy of the measurement remains in the order of 0.1 per cent. However, for measuring the density of water such as brackish water it may be supposed to be comparatively useful. For accuracy we use Nansen's total-immersion pycnometer.[11] K. Hidaka[12] has constructed a new diagram to correct the reading of Akanuma's hydrometer.

Station and layer depth observed.—In order to compare and discuss the records obtained by oceanographic surveys, we should determine as closely as possible the position (latitude and longitude) and the layer depth observed. Frequently, errors owing to uncertainties of determination are remarkably large, and they may lead to an entirely mistaken conclusion (e.g., near the depth of the spring layer in the Japan Sea and the sea south of Hokkaidô, the error of the water temperature frequently amounts to 1° C. and the variation of position 1 sea mile).

Usually the determination of the observing station is made on the basis of a land survey, by the radio-acoustic method, and at times, as in dense fog, dark night, or heavy rain, the sounding method (recently almost by echo) with constant reference to the chart, is adopted. Since errors of determination of position are especially important in a strong-current area such as Kurosio, particular attention is paid to minimizing it.

In order to determine the layer depth accurately, it is intended by suitable steering of the ship to bring sounding wire to the least inclination from the vertical, and after the angle of inclination is measured by means of a specially designed inclinometer[13] the necessary correction is applied to the depth found by the wire gauge.[14] However, at a depth of more than 300 m. a considerable error may generally be produced, owing to the deviation from the vertical of the sounding wire in the subsurface water. Hence the principal research vessels (*Syunpu-Maru*, *Sôyô-Maru*, *Misago-Maru*, etc.) conduct the determination of the true depth and the curve form of the sounding wire in the ocean by means of an unprotected reversing thermometer of the Richter pattern. Z. Nakai[15] has proposed a very convenient diagram for evaluating the depth by the unprotected reversing thermometer, based on the following formulae:

$$h = a\,(t_p - t_w) + \triangle h,\ \triangle h = \left(\frac{10}{K\delta} - 100 \right)(t_p - t_w).$$

Current measurements.—The methods of current measurement adopted by the Hydrographic Department were illustrated formerly by S. Kishindo.[16]

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[10] K. Suda, K. K. I., 24, 1930.

[11] K. Hidaka, Z. Yasui, K. K. I., 66, 1933.

[12] K. Hidaka, U. S., 14, 1934.

[13] K. Hidaka, J. O. Kobe, 2, 4, 1931.

[14] M. Uda, U. S., 14, 4, 1934; Z. Yasui, U. S., 14, 5, 1934; K. Suda, J. O. Kobe, 2, 3–4, 1931.

[15] Z. Nakai, U. S., 15, 2, pp. 53–60, 1935.

Employing the Ekman-Merz current meter, accurate current measurements are taken, in general, by continuous hourly observation during 26 hours at anchor in comparatively shallow depths, and by use of two current meters, one at the upper and another at the lower, at about 800-m. or 1000-m. depths, following the method originated by Helland-Hansen to apply on the high seas.

The influence of the iron-built ship *Syunpu-Maru* on the direction of the magnetic needle of the Ekman-Merz current meter was measured, and K. Hidaka[17] reported that for this ship it does not have much effect on the current direction at depths greater than 5 m. from the surface.

Otto's current meter was conveniently employed in the shallow depths such as Ise Wan.

The investigation of currents by means of drifting bodies has merit according to the method used and the compiling of the reports. It is deemed important in the field of fisheries, especially in order to find the general feature of the increase and decrease of oceanic current.[18]

Hence, a number of drift bottles (postcard enclosed in the bottle), with or without a small drag, have been thrown in the waters seasonally year by year since the first experiment by Y. Wada in 1893, and the percentage of recovery is 5, sometimes about 10 per cent, in the Pacific Ocean, 30–40 per cent in the Japan Sea, and 15–20 per cent in the Yellow Sea. Probably the differences are mainly due to the geographical position and to the currents in the sea.

The method of current measurements by means of the pursuit of current floats is effectively used in the seas neighboring Japan. On estimating the currents from the records of location and the time of thrown-in and picked-up drift nets and long lines in the waters adjacent to Japan, M. Uda[19] proved their value as good current floats and plotted the currents obtained in this way in the North Pacific Ocean.

On the other hand, we can infer the currents from the natural drifting bodies; for example, the currents south of Hokkaidô investigated by K. Seki,[20] the investigation being based on the drift of pumice stone erupted by the Komagadake volcano in June, 1929, and the currents in the tropical region in the Pacific Ocean investigated by H. Kawasaki,[21] this investigation being based on the drift of floating woods.

For the measurement of currents in harbors by the Imperial Marine Observatory, the methods adopted were those of using the air bubbles produced from the hole of a hollow sphere immersed in the water at the side of the motorship, the current meter, and current-floats made of small wooden pieces.

Since the currents computed on Bjerknes' theory coincide well with the results of direct measurements in the Japan Sea and in the Pacific Ocean in general, the importance of the dynamical method is assured. However, in some regions, according to the theoretical researches, the results of the dynamical calculations ought to be modified considerably, as with respect to the currents in the tropical region under the influence of the wind-driven currents, and those in the seas eastward of Honsyu with complicated vortices.

The Honda tidal gauge of the bell type, characterized by elevation of the mercury head in agreement with the variation of water pressure (water level), is equipped at all tidal stations in this country with the tidal gauges of Kelvin's, Richard's, and other types. Moreover, the modified form of this instrument is used in the open sea (at depths less than 150 m.) with a special arrangement for the self-recording of tides over a week's time.[22] On board the *Yodo* the tides in the Yellow Sea were measured continuously with notable accuracy, in centimeters, by means of the successive wire-sounding method with special devices.[23]

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[16] S. Kishindo, S. Y., 10, 10, 12, 1931; 11, 2, 1932.

[17] K. Hidaka, K. K. I., 16, 1928.

[18] S. Y., S. A. O. I. Tokyo, A. R. H. O. Tyosen, S. T. H. Hokkaidô, Nihonkankai Kairyu Tyosa Gyoseki (Osaka Mainiti) 1922.

[19] M. Uda, B. J. S. Sc. F., 3, 2, 1934.

[20] K. Seki, J. O. Kobe, 2, 1, 1930.

[21] H. Kawasaki, U. S., 16, 7, 1936.

Sounding and sampling of bottom deposits.—Although sounding machines of several types are used, such as the Lucas, the Kelvin, and the Sigsbee patterns, and the improved types of them by H. Marukawa, K. Nisida, and others, with devices for the self-control of the wire winding and the protection of the instrument from the water, the instrument in its original form has not yet appeared in this country. In some fishing boats the electric sounding machine is substituted for the windlass attached to the end of a trawl winch. According to experiments of Y. Saito,[24] the sensible maximum depths by the ordinary sounding machine corresponding to the bottom-sampler weights of 14, 22, 30, and 32 kg. are 1500, 2500, 3000, and 4000 m., respectively. The sounding wire made of stranded steel plated with zinc is generally employed.

Comparing the depth obtained by the Warluzel's sounding tube and that by the Lucas sounding machine, K. Hidaka[25] has studied the reason why the depth by the former is always greater than by the latter and has shown that on applying the necessary correction the error may be diminished to about 4 per cent.

The sounding to the sea bottom can be also accomplished by means of the unprotected reversing thermometer attached to the end of the steel wire, to which is attached a hemp rope twenty or thirty meters in length to protect it from kink and breaking. The wire drag is used effectively for searching reefs by the surveying ships of the Hydrographic Department.

The echo sounders now employed in this country are of the Fessenden, Langevin, Admiralty, and other patterns. With respect to the velocity of sound in the sea water as the fundamental element of echo sounding, S. Kishindo,[26] using Heck's Table as a basis, has constructed a correction table of the sound velocity for the variation of the density of sea water due to the difference of water temperature and salinity at each depth. More recently, S. Kuwahara[27] of the Hydrographic Department has rigorously calculated the velocity of sound in sea water from the fundamental equations of thermodynamics and elasticity and has constructed a new table with correction tables which are recognized as the most accurate published.

For collecting samples of bottom sediment there are several types of samplers: Marukawa's snapper, resembling the Monaco pattern; Kitahara's sounding tube, resembling the Sigsbee type; the Kamiya dredge, for the collection of benthic animals and pebbles; and Okamoto's sampler, suitably designed to collect deep-sea mud. A sampler (called the S. K. pattern) suitable for collecting sandy mud in the shallow sea has been invented by M. Sibato and T. Kumada. It is a small dredge consisting of a metallic cone with a knife edge and a cloth bag bound to one end. The bottom samples, after being dried, are sifted by Marukawa's sieves, which resemble the Thoulet pattern.

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[22] K. Kondo, S. Y., 15, 8, 1936.

[23] K. Kunibayasi, Y. Sanematu, S. Y., 11, 4, 5, 1932.

[24] Y. Saito, A. R. H. O. Tyosen, 8, 1938.

[25] K. Hidaka, Mem. Mar. Obs., 4, 1, 1930.

[26] S. Kishindo, S. Y., 14, 12, 1935.

[27] S. Kuwahara, J. J. A. G., 16, 1, 1938; S. Y., 17, 10, 11, 12, 1938.

An original instrument to measure the hardness of the sea bottom has been devised by I. Miura.[28]

The color of the sea and the transparency.—The observation of the color of the sea is commonly made by Forel's and Ule's scales.[29] However, because the colors of these scales do not coincide well with the color tones of Kurosio, trials to find a correct scale have been undertaken.

The transparency of sea water is measured by Secchi's 30-cm. disk, painted white. To measure the turbidity in sea water, an excellent turbidimeter with parallel mirrors and photographic film has been constructed by K. Kimura.[30] S. Yoshimura has discussed the physical meaning of the transparency and has determined the hyperbolic relation between transparency and the quantity of suspended turbid substance.[31]

Y. Takenouti[32] has invented a method of solving the integral equation numerically by the simultaneous observation of the same projected light through several kinds of filters with different characteristics attached to a photocell. R. Sekiguti[33] and his collaborators have described a device for measuring the transmission of light through lake water. It consists of two cylindrical metal vessels containing, respectively, a photocell and an electric lamp. As a result of the observations taken, an abnormally turbid layer in the mid-depth corresponding to the spring layer, has been detected.

Employing the Macbeth illuminator, S. Kamiya[34] has shown on the basis of both experiment and theory that when a constant condition of sky and an apparent color are given, the relation of the degree of transparency to the diameter of Secchi's disk can be found.

Model Experiments on the Mechanism of Currents in the Sea

The results of the experimental researches on vortices carried on by T. Terada, S. Fujiwara, and others have given important clues to the explanation of oceanic phenomena and their mechanism. The line of discontinuity as a train of vortices produced parallel in the line of flow, which was shown by the experiments of T. Terada and his collaborators[35] to be noticeable in great oceanic currents such as Kurosio and the Gulf Stream, and is applicable to the interpretation of the ribbon of hot water, the striped band of cold and warm currents, and "Siome" noted by G. Dietrich, Langmuir, M. Uda, and others.

Regarding the characteristics of "Siome" as a train of horizontal vortices, M. Uda[36] has taken the experiments and studied the displacement of the boundary surface of two liquids varying in the intensity of two opposite currents and the density of those liquids successively.

Also, the mechanism of cellular vortices found by T. Terada is applicable to theories of convection currents in the ocean; for example, the theory proposed by K. Suda[37] that the mechanism of convection in winter in the northern region of the Japan Sea causes the refreshment of the bottom water in that sea.

Of course, we cannot get results quantitatively by a model experiment without the establishment of a law of similitude. However, it is possible to catch the outline of the phenomenon. In the famous research of the secondary undulation of tides in the bays and harbors of Japan by K. Honda, T. Terada, D. Isitani, and Y. Yosida (1908),[38] a model experiment was first undertaken on the ground of the principle of similitude.

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[28] I. Miura, J. I. F. I., 25, 2, 1929.

[29] T. Okada, Tiki Kyoiku, 2, 1925.

[30] K. Kimura, J. I. F. E. S., 1, 1930. Reported in Proc. 5th Pac. Sci. Cong.

[31] S. Yoshimura, U. S., 16, 1, 1936.

[32] Y. Takenouti, B. J. S. Sc. F., 5, 3, 1936.

[33] R. Sekiguti, T. Asahira, T. Kitaoka, K. S., 14, 5, 1936.

[34] S. Kamiya, B. J. S. Sc. F., 4, 6, 1936.

[35] T. Terada and others, Rep. Aeronaut. Res. Inst. Tokyo, 26, 1927; 31, 1928; 53, 1929.

[36] M. Uda, B. J. S. Sc. F., 5, 1, 1936.

[37] K. Suda, J. O. Kobe, 4, 1, 1932.

In the laboratory of the Imperial Marine Observatory model experiments have been carried out with respect to the currents in the seas neighboring Japan subjected to Kurosio—on the wind-driven current by K. Hidaka,[39] and also on the tidal currents in the Harimanada by S. Takaya.[40] By Hidaka's experiment it is seen how the course of Kurosio is modified by the configuration of the Japanese Islands.

M. Okada and S. Miyosi of the Imperial Fisheries Institute[41] have conducted, with elaborate devices, a model experiment on tides and tidal oceanic currents in the Sagami Wan, and have obtained useful results by photography. A model experiment also has been undertaken by T. Isahaya and T. Nakazima of the Hokkaidô Fisheries Experimental Station on the currents of Hunka Wan, to investigate the general feature of the currents.[42]

In the field of harbor engineering, H. Matuo[43] has conducted model experiments on the currents of Urado Wan, Osaka Wan, and Tyosi Harbor, and has contributed to the solution of the problem of sand drift due to the combined effects of waves and current.

It is to be remarked that all the experiments mentioned above lack equipment to show the influence of the deflecting force due to the earth's rotation, which should be submitted to future study.

INVESTIGATIONS OF THE BOTTOM OF THE SEA

The depth of the sea.—For more than half a century, soundings in the waters adjacent to Japan have been made by the Hydrographic Department and the Imperial Japanese Navy, and a number of sea charts have been published and are constantly renewed as the data increase. Especially in recent years have data been rapidly accumulated by means of echo sounding.

Remarkable mapping work for the bathymetric chart (Chart No. 6080, revised in 1936) in the seas adjacent to Japan have been accomplished as discussed in the reports of S. Ogura[44] and R. Sigematu,[45] based on the sounding data obtained by the surveying ships *Mansyu, Komahasi, Kosyu,* and others. In particular, Japan Trench (formerly called the Tuscarora Deep) was plotted completely, and is discussed in detail. The Japan Trench is far narrower and deeper than was formerly supposed, and its deepest portion, of 10600 m. is called the Ramapo Deep and is located in the vicinity of the former deep of 9435 m.

R. Sigematu has reported the complex configuration of the sea bottom in the southern Japan Sea and of the Mariana Trench. He divided the crescent form of the Mariana Trench into three portions, and the Caroline Basin into west and east portions. He also found that the Yap Ridge is continued to the Mariana Ridge, that the ridge lying to the north of Palau stretches to Oki-no-Torisima, and that the banks of depths 270 m. and 324 m. (Koho Tai) are to the east of O-Agari-Sima.

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[38] K. Honda, T. Terada, and others. J. Col. Sc. Tokyo Univ., 24, 1908.

[39] K. Hidaka, Geophys. Mag., 1, 3, 1927; 1, 4, 1928.

[40] S. Takaya, K. K. I., 28, 1930.

[41] M. Okada, S. Miyosi, J. I. F. I., 29, 1, 1933; 30, 4, 1935.

[42] T. Isahaya, Y. Nakazima, Decad. Rep. Hokkaidô Fish. Exp. St., 1934.

[43] H. Matuo, Doboku Sikendyo Hokoku, 41, 1938.

[44] S. Ogura, S. Y., 4, 4, 1925; *idem,* Proc. 5th Pac. Sci. Cong., 1933.

[45] R. Sigematu, R. O. W. J., 6, 1934; 5, 2, 1933.

M. Matuyama[46] has found a train of anomaly of gravity distributed parallel to the Japan Trench by the survey on submarine boat. Also, H. Yabe,[47] R. Sigematu, S. Ogura, and others have discovered a number of sea valleys (drowned valleys) in the seas adjacent to Japan, which are important not only as a fault line and an indicator of subsidence in geological time, but also to present-day fisheries.

Since the reefs and banks in the seas are highly evaluated as good fishing grounds in general, many fishing boats are engaged in their investigation. Recently the *Soyo-Maru* of the Imperial Fisheries Experimental Station discovered a new bank[48] at 29° 51′ N, 133° 21′ E (depth 209 m.),[49] to the northeast of O-Sima in the Sagami Wan, and a new ridge branching from the ridge of Oki-no-Simato Yamato-Tai in the Japan Sea.[50] Kosyu-Tai or Kinan-Syo (depth 710 m.) and Koho-Tai are notable as fishing grounds of tunny and bonito.

Both Syunpu-Tai (depth 465 m.), found by *Syunpu-Maru* of the Imperial Marine Observatory in 1930, and the shallow portion of 795 m. depth found by *Soyo-Maru* in 1932, are included in a large bank newly named "Kita-Yamato-Tai"[51] (its shallowest depth 418 m.) lying parallel to the north of Yamato-Tai[52] (its minimum depth 285 m.) by the detailed survey of the *Yamato*.[53]

The Fisheries Experimental Station of the Government-General of Tyosen has paid particular attention to sounding work in the Japan Sea. In particular, it should be noted that under the leadership of K. Nisida,[54] by wire sounding aboard the *Misago-Maru*, a new record of the deepest part, 4049 m., of the Japan Sea was obtained in 1934, inclination of the wire amounting to 11° to the vertical at that time at the station at 43° 0′ N, 137° 39′ E. Summarizing the data obtained by the *Misago-Maru*, the *Hayabusa-Maru*, and the *Otori-Maru*, belonging to the same office, Y. Saito[55] plotted an elaborate bathymetric chart for the seas along the east coast of Tyosen in which three newly found banks are described.

From cartographical computation on the basis of a new bathymetric chart plotted by M. Uda[56] in the Japan Sea, a mean depth of 543 m., an area of 1302 x 10^2 km.^{2}, and a volume of 113 x 10^3 km.^{3} have been shown. Similar geomorphological computations have been made in Seto-Naikai by Z. Yasui,[57] in Sagami Wan by M. Uda,[58] in other bays by S. Yoshimura,[59] and in the adjacent seas of Tyosen by the Fisheries Experimental Station of Tyosen.[60] T.

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[46] M. Matuyama, Proc. Imp. Acad., 12, 4, 1936.

[47] H. Yabe, R. Tayama, R. O. W. J., 2, 1929.

[48] M. Uda, K. Imamura, S. Y., 17, 8, 1938.

[49] K. Imamura, G. Okamoto, S. Y., 13, 9, 1934.

[50] M. Uda, J. I. F. E. S., 7, 1936.

[51] S. Y., 12, 10, 1933; H. Niino, Tisitugaku Zassi, 42, 506, 1935.

[52] S. Y., 5, 11, 1920.

[53] Beginning from the discovery made by the *Tenyo-Maru* of the Imp. Fish. Exp. Inst. in July, 1921, of three shallow depths of 307–472 m. at the center of the Japan Sea, in the summer of 1924, the *Yamato*, under the command of Captain R. Sigematu, took detailed soundings and brought the whole form of the bank to light. Afterwards the value of the bank as a fishing ground was ascertained by the expedition of the Hukui Fish. Exp. St.

[54] K. Nisida, U. S., 15, 3, 1935.

[55] Y. Saito, Bul. Fish. Exp. St. Gov.-Gen. Tyosen, 5, 1937.

[56] M. Uda, J. I. F. E. S., 7, 1936.

[57] Z. Yasui, K. K. I., 29, 1930.

[58] M. Uda, J. I. F. E. S., 8, 1937.

[59] S. Yoshimura, T. Z., 46, 1934.

[60] Tyosen Kaiyo Benran, 1936.

Terada has affirmed the importance of the bathymetric chart by many geophysical researches in the Japan Sea,[61] Tosa Wan, Sagami Wan, etc.

Now in the Pacific Ocean we see a broad area of unexplored sea bottom. The future map, filled by the data to be obtained in such a region, will give us a complicated configuration of sea bottom different from the plain one shown on the older maps.

The marine deposits.—With regard to the bottom sediments collected by the surveying ship *Mansyu* in the Pacific Ocean, we have the reports by S. Hanzawa,[62] S. Syozi,[63] and others in which the distribution of the classified bottom deposits by microscopical and chemical analysis are given in detail, particularly with the analysis of calcium and radium[64] contents. I. Kumada[65] has mapped the distribution of deposits in the Polynesian South Sea.

The vertical distribution of the bottom sediments in the Japan Sea has been described by M. Uda[66]—the terrigeneous sandy zone at depths less than 150 m., the blue mud zone from 200 m. to 1500 m. depth, the upper red and the lower blue mud zone from 1600 m. to 3000 m. depth. Detailed geological studies of the samples collected by the *Soyo-Maru* in the Japan Sea have been made by H. Niino.[67] The origin of the wonderful pipelike concretion in the shallower sea bottom on the continental slope first found by H. Niino[68] and afterwards reported by Y. Saito[69] in the Japan Sea is yet unknown. The many geological investigations on the banks and reefs (e.g., Musasi-Tai,[70] Yamato Tai,[71] Gentatu No-Se, Se-no-Umi,[72] etc.) carried out by H. Niino have been fruitful, particularly with respect to the pebbles on the bank.

Of the relation between the deep-sea current and the physical, chemical, and biological characteristics of the bottom sediment as already shown by the *Meteor* expedition in the Atlantic Ocean, scarcely anything is known respecting the seas surrounding Japan.

WATER MASSES IN THE SEAS ADJACENT TO JAPAN

One water mass can be distinguished from another because its attributes (water temperature, salinity, etc.) are peculiar and homogeneous. Accordingly, the analysis of a water mass is usually made by means of the distribution curves of water temperature, salinity, color of the sea and transparency, dissolved oxygen, and density *in situ*, or by the thermohaline curve after the method of P. Jacobsen.

The general monthly distribution of the surface-water temperature in the Pacific Ocean was first plotted by Y. Wada (1904),[73] next by T. Okada (1924),[74] and then by K. Suda (1929–30)[75] and Z. Tukuda (1935),[76] the investigations being based on the materials noted on the logbooks which have been collected by the Imperial Marine Observatory and by the Central Meteorological Observatory.

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[61] T. Terada, Bul. Earthq. Res. Inst. Tokyo, 12, 4, 1934.

[62] S. Hanzawa, R. O. W. J., 1, 1929.

[63] S. Syozi, Tohoku Imp. Univ. Rep. Geol., 29, 1938.

[64] H. Hamaguti, M. Isihasi, Y. Harada, Nihon Kagaku Kaisi, 59, 1938.

[65] Hayatomo Fish. Inst., S. Y., 13, 1934.

[66] M. Uda, J. I. F. E. S., 5, 1934.

[67] H. Niino, T. Z., 45, 533, 1932; *idem*, J. I. F. I., 29, p. 103, 1933.

[68] H. Niino, J. Z., 45, 528, 1932.

[69] Y. Saito, Rep. 1933, F. E. S. Tyosen.

[70] H. Niino, Geo. Rev., 12, 2, 1936.

[71] H. Niino, Tisitugaku Zassi, 40, 473, 1932.

[72] H. Niino, J. I. F. I., 29, 2, 1934.

[73] Y. Wada, Geophys. Mag., 1, 1904.

[74] T. Okada, Mem. Mar. Obs., 1924.

[75] K. Suda, J. O. Kobe, 1, 1, 2, 3, 1929, 1930.

[76] Z. Tukuda, Y. Yosikawa, K. K. I., 84, 1935.

To meet the demands of the fisheries investigation, M. Uda[77] plotted the normal distribution of the water temperature and salinity at the surface and at the depth of 100 m. in the waters adjacent to Japan, averaging the records obtained by the regular sectional observations during the past twenty years. K. Nisida (1936)[78] constructed similar charts, particularly for the seas adjacent to Tyosen.

Special investigations on the normal hydrographical conditions of the Japan Sea, Yellow Sea, Okhotsk Sea, Pacific Ocean, and Seto Naikai were carried out by M. Uda,[79] who plotted the monthly variation of the color of the sea,[80] the transparency,[81] the water temperature, and the salinity of the surface and subsurface layers, pointing out several water masses characteristic of the sea on the basis of the thermohaline curves.

Normal seasonal water temperature was indicated by the Hydrographic Department in its Chart No. 6031. Normal monthly water temperature and salinity is indicated in the Monthly Oceanographical Chart issued with constant revision, by the Imperial Fisheries Experimental Station.

Of course, it is difficult for a single surveying ship to make perfect records in a broadly extended sea region, because the variation of the hydrographical conditions affects the data collected during the interval of observation. It is best to conduct simultaneous surveys with a number of surveying ships all following the routine line in accordance with a systematic method.

The water masses in the Japan Sea.—Simultaneous observations were carried out with the collaboration of fifty boats (*Soyo-Maru, Tankai-Maru, Misago-Maru,* etc.) belonging to the fisheries authorities in Japan for a period about June 5, 1932[82] and of thirty boats about November 5, 1933.[83] The summarized results of the investigation have been reported by M. Uda. The *Syunpu-Maru* of the Imperial Marine Observatory made a survey in the Japan Sea in the summers of the years 1928–1932 and the results were reported in the *Journal of Oceanography.*[84] Besides these, surveys were conducted in the Japan Sea by the surveying ship *Yamato* and by the *Misago-Maru* in 1933 and 1934.[85]

By an investigation in the spring of 1932 in the Japan Sea, the cold-water mass of salinity 33.7–34.2 per cent and the warm-water mass belonging to the Tusima Current System of salinity 34.3–34.8 per cent were found to come in contact with each other. By a survey made in the autumn of 1933 we see that in the upper layer above the 25-m. depth the water mass of low salinity from the Yellow Sea and the Eastern China Sea flows into the Tusima Strait after June, an abundance of it is transported into the Japan Sea by the East Tyosen Warm Current, and the comparatively saline and transparent water mass is displaced in the northeastern region of the Japan Sea west to Hokkaidô. In the intermediate layer, from depths of 50 m. to 100 m., we see the warm and saline water mass belonging to the Tusima Warm Current System (occupying the southern part of the sea), in which the content of nutrient salts and dissolved oxygen is scanty and shows higher values of pH, facing the cold and less saline water mass occupying the northwestern part of the sea, which contains plenty of nutrient salts and dissolved oxygen and less alkaline. An arc-shaped line of discontinuity runs through the central part of the Japan Sea, beginning at the cape of the Gaizitu Bay in Tyosen and ending in the region about 40 statute miles to the west of Tugarù Strait. The water mass of the Liman Cold Current System, represented in the western area of Karahuto, is distinguishable from the water mass of the North Tyosen Cold Current System.

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[77] M. Uda, G. Okamoto, J. I. F. E. S., 1, 2, 1930, 1931.

[78] Fish. Exp. St. Tyosen, 1936.

[79] M. Uda, J. I. F. E. S., 5, 1934; *idem,* J. I. F. E. S., 3, 79–136, 1933; M. Uda, N. Watanabe, J. I. F. E. S., 3, 1933.

[80] M. Uda, U. S., 10, 8, 1930.

[81] *Ibid.*

[82] M. Uda, R. O. W. J., 6, 1, 1934; *idem,* J. I. F. E. S., 5, 1934. At that period the hydrography in the Kurosio region was described by K. Koenuma, J. O. Kobe, 5, 2, 1933.

[83] M. Uda, J. I. F. E. S., 7, 1936.

[84] J. O. Kobe, 1930–1934.

[85] A. R. H. O. Tyosen.

From the distribution of water temperature and salinity, dissolved oxygen, nutrient salts, and so on, conspicuous upwelling of the lower water mass is inferred in the region west of Tugaru Strait, in the vicinity of Yamato-Tai, and at the east of Tusima Island.

In the stratification of the water masses in the Japan Sea we distinguish three layers: the upper layer (warm and less saline), from the surface to 25 m. depth; the intermediate layer, from 25 to 200 m. depth, including the nucleus of the highly saline and relatively warm water belonging to the Tusima Warm Current; and the lower layer, below 200-m. depth. The last-mentioned deep water is characteristic of the Japan Sea, with nearly uniform properties, that is, warm temperature of about 0.1°–2° C. and salinity of 34.0–34.2 per cent (about 34.1 per cent on the average). At the depth from 1000 to 1500 m. the minimum water temperature of 0.1°–0.15° C. is observed.

The distribution of the nutrient salts shows a higher value in the upper layer in the cold water area on the continental side, contrary to the lower layer below the 200-m. depth, being more fertile on the side of Japan Proper than on the continental side.

It is an astonishing fact that remarkably high values of dissolved oxygen (about 6 cc/l.) and high percentage of saturation (about 75 per cent) are found in the deep water of the Japan Sea. This shows a marked difference from the distribution in the Pacific Ocean and in the Okhotsk Sea (O_2 less than 2 cc/l. at 1000 m. depth).

At the entrance of the Tusima, Tugaru, and Soya straits, which have depths of 100–200 m. on the average, the characteristic water of the Japan Sea basin is completely separated from the waters of the Pacific Ocean and the Okhotsk Sea.

The production of the characteristic water mass should be due to the sinking of the upper water in winter and on the continental side by active vertical convection. According to K. Suda,[86] the increase of the density due to the marked cooling of the surface water in winter and that due to the separation of a salty mass produced at the time of freezing may produce the agency convection.

The refreshment of the bottom water may be slowly brought about by the general circulation accompanied by the sinking mentioned above.

The translation of the salty water mass from spring to summer and that of the water mass of low salinity flowing in summer from Tusima Strait to the north has a velocity of 0.3 knot.

In the Yellow Sea a conspicuous spring layer is formed in summer at a depth of about 15–30 m. and the water temperature and salinity are 20°–30° C. and 31–31.5 per cent in the upper layer, 7°–10° C. and 32.2–32.5 per cent in the lower layer. The routine observation by the Nagasaki Meteorological Observatory between Nagasaki and Shanghai affords useful data also.[87]

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[86] K. Suda, J. O. Kobe, 4, 1, 1932.

The northern region of the North Pacific Ocean.—In the North Pacific Ocean over the area up to 1000 statute miles from the coast, simultaneous oceanographic surveys have been continued each summer since August, 1933, by the research vessels (10 to 20 boats in number) belonging to our fisheries authorities.[88] As a result of these surveys, a remarkable low temperature in the North Pacific Ocean in the summer of 1934 as compared to that of 1933, particularly in the upper layer above the 150-m. depths in the zonal area around the line of 40° N., was found and was associated closely with the cool summer and poor rice crop in northern Japan—phenomena already experienced repeatedly in the past. Beginning, therefore, in the following year, 1935, similar simultaneous surveys were made in January, February, March, and November, in addition to August as before, in order to obtain data for forecasting the anomaly of the water temperature in summer for the benefit of the agricultural and fisheries authorities.[89]

As can be determined from the water temperature, salinity, color of the sea, transparency, dissolved oxygen and silicate content, and so on, a line of discontinuity, stretching from the southwest to the east of the sea region of Sanriku, shows a wavy form and limits the boundary of the northern water mass belonging to the Oyasio Cold Current and the southern water mass belonging to the Kurosio Warm Current.

The characteristics of the Oyasio water mass are coldness (water temperature 15° C.), less salinity (below 34 per cent), turbidity (the color of the sea is IV–VIII on Forel's Scale, and the transparency is less than 10 m.), the dissolving of plenty of oxygen in the upper layer (frequently more than 6 cc/l. and always supersaturated), and richness in the nutrient salts of plankton (especially in the silicate content corresponding to the abundance of diatoms). On the contrary, the Kurosio water mass is warm (15°–30° C.) and highly saline (34.5–35.3 per cent), transparent (usually of transparency above 25 m., the color of the sea I–II on Forel's Scale), relatively poor in dissolved oxygen (in the upper layer O_2 above 5 cc/l.), more alkaline (pH about 8.3) than the Oyasio water mass, and scanty in nutrient salts (especially poor in silicate content).

In the stratification of water in the Kurosio area we can distinguish the following water masses: (1) the mass in the surface layer down to the 25-m. depth, of warm (20°–30° C.), less saline (less than 34.5 per cent) water; (2) the nucleus of the Kurosio water in the subsurface layer centered at depths from 50–100 m., which is relatively warm (15°–20° C.) and highly saline (34.5–35.3 per cent); beneath it the intermediate layer (dichohaline), of temperature 5°–8° C. and salinity 33.5–34 per cent, lying usually at depths of 600–800 m. in the southern sea [tracing the central nucleus depth, it becomes shallower and continues to the north until the upper layer of Oyasio]; and (3) the cold (2°–5° C.) and comparatively saline (exceeding 34.5 per cent) deep water lying at depths from 1300 to 1500 m. Next, in the stratification in the Oyasio water mass, there are (1) the surface mass belonging to the Oyasio Cold Current, in depths from 0 to 25 m., of cold (below 15° C.) and comparatively fresh (salinity less than 33.5 per cent) water; (2) the dichotherm water mass corresponding to the nucleus depth of the Oyasio water, centered at depths from 50 to 200 m. (usually minotherm at 100–150 m. depth), of remarkable cold (0°–2° C.) and less salinity (about 33.3 per cent); (3) the methotherm water mass, of temperature 3°–4° C. and salinity about 34.1 per cent, lying in the layer at the depths from 500 to 800 m.; and (4) beneath them, at about 1500 m. depth, the deep water of temperature 2°–3° C. and salinity 34.4–34.6 per cent.

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[87] Y. Matsudaira, Z. Yasui, J. O. Kobe, 4, 1, 1932.

[88] M. Uda, J. I. F. E., 6, 1935.

[89] M. Uda, J. I. F. E. S., 9, 1938.

The water mass of the dichotherm layer is found not only in the Oyasio region but also in the Okhotsk Sea, and is especially conspicuous in the region along the east coast of Karahuto. It is a mass with temperature below 0° C. and frequently below —1° C., called the "negative temperature zone," and is supposed to move in a counterclockwise direction in the sea, lying, according to K. Suda,[90] just beneath the freezing region in winter.

From the coincidence of water temperature and salinity, dissolved oxygen (about 7 cc/l.) and density *in situ,* the dichotherm water is identified by M. Uda[91] with water mass lying in winter in the surface layer of the Oyasio region adjacent to Tisima and in the Okhotsk Sea. It is the water mass which sank down to the mid-depth because of vertical convection in the upper layer in winter, caused by air cooling at the sea surface, and is detected in summer, when the upper water is warmed by the influence of the solar radiation and the warm current. As for the dichotherm layer found in the region off the south coast of Hokkaidô, Aomori, Iwate, and Myagi Prefecture, although one part of the water mass sank from the surface layer of that region in winter, the main part of it was transported by the Oyasio Current coming from the water in the Okhotsk Sea and the seas adjacent to Tisima in winter.

According to K. Suda,[92] the water masses in the northern seas (Okhotsk Sea, Bering Sea, etc.) can be classified into (1) surface water of low salinity, warm in summer and of thickness 10–20 m.; (2) the water in the dichotherm layer mentioned above; and (3) the water in the methotherm layer. The origin of the last-named layer is as yet obscure.

The southern part of the North Pacific Ocean.—Surface observations across the entire Pacific Ocean have been made on board the *Sintoku-Maru* as reported by Y. Matsudaira,[93] and observations to depths of 400 m. on board the *Hakuyo-Maru,* as reported by S. Saito.[94]

Basing his work on the survey of the *Soyo-Maru* in 1928–1929, M. Uda[95] has classified the water strata in the Kurosio region around the Izu Island as (1) the water mass in the upper layer, from the surface to 200 m. depth, belonging to the Kurosio Water (warm and salty, centered at 100–150 m.); (2) the Intermediate Water at depths 400–900 m., cold and of low salinity (about 34.3 per cent), centered at depths 500–600 m. on an average; and (3) the Deep Water of temperature 2°–3° C., relatively saline, lying below 1000 m. depth. At about 400 m. depth an abrupt change of temperature and salinity has been observed.

The winter investigations of 1929–1935 by the *Soyo-Maru* in the Sagami Wan[96] have determined (1) the upper layer, above the depth of 300 m., including the Kurosio Water (temperature 17° C., salinity 34.75 per cent, centered at 100 m. depth) as its nucleus; (2) the intermediate layer, at depths 300–1000 m., including the water mass belonging to the Oyasio undercurrent (centered at about 600 m. depth, temperature 5.5° C., salinity 34.3 per cent) as its nucleus; and (3) the deep water, below 1000 m. depth, nearly of a temperature of 3° C. and of salinity 34.55 per cent.

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[90] K. Suda, Suisangaku Zassi, Hakodate, 41, 1937.

[91] M. Uda, U. S., 15, 12, 1935.

[92] See note 90 above.

[93] Y. Matsudaira, J. O. Kobe, 1929–1938.

[94] S. Saito, S. K., 29, 5, 1934; 32, 2, 1937.

[95] M. Uda, R. O. W. J., 2, 2, 1930.

[96] M. Uda, J. I. F. E., 8, 1937.

Of the water masses in the uppermost layer, above 100 m. depth, in the region around the Izu Islands and in the Sagami Wan, water of remarkably low salinity is observed in summer, as for example the Deckschicht.

A survey in the Kurosio Water extending from the region south of Kagosima Prefecture to the neighboring waters of Ryukyu was made by the *Syunpu-Maru* in the summers of 1933–1935.[97] As a result of the stratification of the water masses in that area, it was found that the surface water (23°–30.5° C., 33–34.7 per cent) extended down to the first discontinuity layer at depths of 50–100 m.; the water mass belonging to the main current of Kurosio (23°–10° C., 34.7–34.9 per cent), between the second and third discontinuity layers (at a depth of about 900 m.); and the water mass belonging to the Pacific deep current (2.6°–5° C., 34.4–34.5 per cent), below the third discontinuity layer.

Treating the materials in the reports of the *Mansyu* expedition[98] after the method of Jacobsen's analysis on the basis of the thermohaline curves, K. Koenuma[99] has discussed in detail the characteristic water masses in the southwestern part of the North Pacific Ocean and their origins. The haline water mass in the North Pacific Ocean seems to originate in the surface area between 160°–180° E and 20°–30° N. Its water temperature shows a relatively great seasonal variation, while its salinity varies little. A part of this water is moved westward by the northeast trade wind in autumn, and in winter it sinks to about 150 m. depth to produce the original form of the haline water in this region. The haline water which appears in the tropical region of the western Pacific originates in the surface area north of 20° S and east of 180° E, and is then driven by the southeast trade wind. North of 10° N, the water between the surface and the intermediate layer is the mixture of the different waters in various ratios, and the upper part of this mixture seems to be the most haline water of any area. The Kurosio water belongs to this part of greatest halinity. Further, Koenuma has distinguished two kinds of Kurosio: one flows northeastward, as is generally believed, in the east China Sea, and comes to the south of Sikoku; the other flows in a northeasterly direction to the northeast of Minami Oagari Zima. He has concluded that the two apparently unite at the south of Sio-no-Misaki, where the Kurosio is most distinct.

The coastal and inland sea water.—Being an admixture of the fresh land water and the saline oceanic water, the coastal water lying on the continental shelf at depths less than about 200 m. has in general a complex constitution, subjected to topographical and the meteorological conditions in addition to the influence of the oceanic current. S. Yoshimura[100] has computed, by measuring silicate and salinity, the ratios of the three components of coastal water—land water, oceanic water, and the water due to precipitation. Using the equation of continuity on the data of silicate and salinity in the Sagami Wan, M. Okada[101] has extended Knudsen's theorem three-dimensionally and distinguished the upwelling and sinking regions in that bay.

From a detailed investigation of the coastal waters surrounding the Japanese Islands by K. Suda,[102] it has been found that the time variation of the coastal water is related to the variation of the land drainage, and further, on inspection of the monthly variation of the coastal water in those regions that the predominant season in the Oyasio region is about in May; that with respect to the yearly variation of the coastal water the maximum in 1923 and the minimum in 1926 are conspicuous; and that the ultimate cause of variation lies in the precipitation. M. Uda and N. Watanabe[103] have shown that since the salinity in Seto Naikai has negative correlation with the precipitation of one or two months earlier, a forecast of salinity can be made. As extremes, we have for the salinity in Seto Naikai in the summer of 1934 an abnormal increment of 1–3 per cent owing to the drought in that year, and in the summer of 1938 an abnormal decrement of 2–5 per cent owing to the heavy rain and flood.

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[97] J. O. Kobe, 11, 1, 1938.

[98] Hydr. Dep., B. H. D., 6, 1933.

[99] K. Koenuma. Mem. Nat. Obs., 6, 4, 1938; *idem,* U. S., 16, 4, 1936; 17, 4, 1937.

[100] S. Yoshimura, Gerlands Beitr. z. Geophys., 34, 1931.

[101] M. Okada, B. J. S. Sc. F., 3, 3, 1934; 3, 5, 1935.

[102] K. Suda, U. S., 14, 10, 1934, pp. 336–342.

The fundamental cause which varies the influence of the coastal water lies in the fluctuation of the amount of land water supplied in the sea, as well as the influence of the oceanic water adjacent to the coastal region. The remarkable change resulting from the invasion of oceanic water is mentioned in Section VIII below.

The coastal water transported by the coastal current tends to accumulate in the vortical region corresponding to some topographical conditions inside the boundary line formed against the oceanic water, where the mixing of the oceanic water is feebly influenced. Such a region coincides almost always with the region of convergence. Moreover, such a boundary line acts as a fence net and accumulates the shoals of fish, where the content of nutrient salts are abundant and swarms of infant fishes and plankton are seen. At length the coastal region is regarded as a good fishing ground (an example is the coastal region near Cape Manaduru in Sagami Bay). The vortical regions lying north and south of the mouth of Tone River, as shown from the experimental researches by H. Matuo,[104] correspond to the good fishing grounds of sardine. It is already evident that the shoals of fish (sardine, mackerel, yellow tail, etc.) are condensed or introduced by the invasion of oceanic water into the coastal water. The invasion of oceanic water changes the coastal water by mingling and at length drives it away. Conversely the fluctuation of the coastal water has much influence on the variation of oceanic current, as pointed out by K. Suda.[105]

Moreover, the conditions of coastal or inland water may vary abnormally with severe cold and with stormy weather. In Seto Naikai, according to the reports of the local Fisheries Experiment Station in January, 1934, the water temperature, corresponding to the severe coldness, is 1° C. lower than that of the normal year, in particular the lower layer in Kii Suido, which is 2° C. lower than the normal one. The floating of the frozen bottom fish (Tai, etc.) were found in such regions as the southern coast of Kii, where the variation of temperature is remarkable, owing to displacement of the contact zone of oceanic and inland water, and in the vicinity of Naruto, where the influence of the air cooling reaches down to the bottom because of the violent tidal current. A similar phenomenon in the Taiwan Kaikyo in that year was reported by I. Hayasaka. Also in 1936, the sea water in Seto Naikai in January and February, corresponding to the severe winter, was cold and of low salinity, especially in Harima Nada, where the water temperature was 4° C. lower than that of the preceding year, and 2° C. lower than the normal, and as a consequence of it an extraordinary phenomenon was seen in late January when a number of frozen Tai floating over the sea were picked up by the fishermen. We should note the fact that the salinity of 0.5 per cent (locally 1 per cent) lower than the normal in 1936, and also in 1934, is not due to the severe winter, but to the feeble inflow of the warm water from Kii Suido on account of the abnormal retiring of Kurosio to the south in winter.

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[103] M. Uda, N. Watanabe, J. I. F. E. S., 3, 1933.

[104] H. Matuo, Doboku Sikenzyo Hokoku, 41, 1938.

[105] See note 102 above.

The mixing of the water masses aroused by stormy weather has been described by T. Hayasi,[106] K. Kimura,[107] and M. Uda.[108] With the stirring up of fine deposits on the bottom ("Nuta"), the sea becomes turbid and of a yellowish tint which is noticed as a good indication of "Buri" fishing in the season. According to K. Kimura,[109] "Nuta" is found most frequently in the convection period centering around February, and with stratification in spring it nearly disappears.

Of course, when there are heavy rains, muddy water is carried into the coastal seas. According to the researches of T. Nomitsu and T. Takegami,[110] the sedimentation of mud transported by a river is accelerated when it meets sea water; that is, the mud particles coagulate under the ionic action of sea water and settle down rapidly. Microscopic and chemical studies of the sea off the Yangtze River have been made by Y. Matsudaira.[111]

In the coastal region of Japan on the Pacific side, during the early spring (March and April) of each year, the sea water shows conspicuous turbidity and usually a pale bluish color which is called by fishermen "the sea water corrupted." In the sea adjacent to Iwate Prefecture an extreme occurrence of this phenomenon, called "Yaku Midu," has been investigated by T. Hayasi,[112] H. Marukawa,[113] and the Iwate Fisheries Experimental Station. The cause of the extreme turbidity lies chiefly in the sudden increase of phytoplankton (mainly diatoms), which reaches its maximum quantity in the spring, except when due to snow-melted muddy water. K. Kimura[114] states that the variation of transparency in the coastal water, which has a period of nearly half a month, may be due to the invading oceanic water accompanying the spring tides. He also describes the remarkable water temperature keeping pace with the tidal current.

RESULTS OF THE INVESTIGATION OF CURRENTS

Currents as an important factor affecting navigation and fisheries are now zealously investigated in Japan, especially the well-known currents such as the Kurosio, Oyasio, and Tusima. On the development of mathematical theory concerning density current, slope current, and wind-driven current, many contributions have been made by K. Hidaka,[115] T. Nomitsu,[116] and others.[117] On the other hand, the practical method of calculation based on observed oceanographic elements such as temperature, salinity, and dissolved oxygen, have been studied by M. Okada.[118]

The scattering of drift bottles in the ocean current has been discussed by M. Uda theoretically.[119]

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[106] T. Hayasi, Riken Iho, 12, 1, 1933.

[107] K. Kimura, R. O. W. J., 5, 2, 1933.

[108] M. Uda, N. Watanabe, B. J. S. Sc. F., 6, 5, 1938.

[109] K. Kimura, B. J. S. Sc. F., 4, 1, 1935.

[110] T. Nomitsu, T. Takegami, R. O. W. J., 9, 1937.

[111] Y. Matsudaira, J. O. Kobe, 4, 1, 1932.

[112] T. Hayasi, Suisan Kai, 625, 1935.

[113] H. Marukawa, Suisan Kenkyusi, 1939.

[114] K. Kimura, B. J. S. Sc. F., 1, 3, 1932; 4, 5, 1936.

[115] K. Hidaka, Mem. Mar. Obs., U. S., 1930–1938.

[116] T. Nomitsu, Mem. Col. Sc. Kyoto Imp. Univ., 1932–1938.

[117] The general circulation in the ocean was treated mathematically by H. Arakawa.

[118] M. Okada, B. J. S. Sc. F., 5, 6, 1937; 6, 1, 1937; 5, 1938; 3, 3, 1934; 3, 5, 1935; 5, 2, 1936.

[119] M. Uda, B. J. S. Sc. F., 4, 5, 1936.

Summarizing the published materials in the Japan Sea, the Pacific Ocean, and the Okhotsk Sea, and plotting the distribution of the stream lines after the method of Sandstrom, K. Suda[120] has discussed the dissipation of energy in the ocean currents from the distribution of the eddy viscosity.

Charts showing the synthetic currents in the four seasons in the Pacific Ocean have been published by the Hydrographic Department (revised chart No. 6031, 1936). The reports of currents for the decade are shown in Kairyu Tuho.

Kurosio or Japan Current.—Kurosio, as described in Suio Si, is a great oceanic current which flows strongly toward the northeast along the Pacific side of the Japan Islands east of Taiwan to east of the Sanriku region; and hitherto it has been considered as the elongation of the North Equatorial Current.

The color of the Kurosio water, as its name indicates, is a very beautiful cobalt blue of a slightly black tint, nearly of Forel's scale number I–II, and its transparency is above 25 m., frequently reaching more than 40 m.

The North Equatorial Current, the current driven by the trade wind, having a breadth of less than 250 statute miles and a velocity of less than 1 knot, passes through the region, 10–15° N, north of Truck and Palau islands, and branches to the north and south near Samar Island.

From the sea east of Taiwan to the sea north of Amani, Osima, the Kurosio has a velocity of 1 to 3 knots and a breadth of less than 150 statute miles, and the farther north it proceeds the more its breadth decreases and its velocity increases. According to the *Syunpu-Maru* survey,[121] Kurosio flows toward the north off the west coast of Ryukyo, with a breadth of 70–80 statute miles, and crosses the Tokara Strait to the east. The nautical importance of the Kurosio branch passing through Osumi Strait in a northeasterly direction has been remarked by R. Sigematu.[122] From the sea region south of Kagosima Prefecture to the east of Tiba Prefecture, about latitude 25°–36° N, Kurosio has a velocity of 2–3 knots as an average (along its strongest major axis 3–4 knots, according to S. Kishindo)[123] and a breadth of less than 100 statute miles. From the region of Tiba Prefecture to the region of about 170° E it shows two or three branches and its velocity decreases to 1–2 knots. This is frequently called the North Pacific Current, and it is considered that the westward drift is markedly influenced by the winter monsoon.

Comparing results obtained by actual measurement of the current and by dynamical calculation, it is found that Kurosio has mainly the character of a density current similar to the Gulf Stream, as formerly pointed out by G. Wust, and is but little influenced by the wind-driven current.

However, contrary to the old view, we now agree to the concept of varying water masses in Kurosio; that is, though the streamlines be continuous, mingling and transformation act on the water masses and modify them, as is shown by the analysis of K. Koenuma.[124]

From the existence of swirls in the Kurosio area, including one of clockwise rotation 100 statute miles south from Sio-o-Misaki (its center about 30° N, 136° E), S. Kishindo[125] inclines to the view that Kurosio may be considered as a compound of several vortical currents. There is no doubt that the mingling of sea waters of low salinity in the China Sea, which are especially evident in the summer season, accompanied with the mingling of coastal waters, produces the heterogeneity of the Kurosio water, and the vortical currents above mentioned influence the strength and the course of Kurosio.

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[120] K. Suda, Geophys. Mag., 6, 3, 1932; 10, 2, 1936.

[121] J. O. Kobe, 13, 1, 1938.

[122] R. Sigematu, S. Y., 14, 3, 1935.

[123] S. Kishindo, S. Y., 10, 10–12, 1931.

[124] K. Koenuma, Mem. Mar. Obs., 6, 3, 4, 1937, 1938.

[125] S. Kishindo, 4th Pacific Sci. Cong., Rep., 1929.

Kurosio cannot now be considered, as formerly, merely as a great river in the ocean. Abnormal variation of Kurosio since 1936 has been noted in the sea south of Japan, and a peculiar cold-water mass[126] appearing in the region about 100 statute miles south of Sio-no-Misaki, with a counterclockwise rotation, has deflected its course in a northerly direction from the region near Hatidyozima.[127] A remarkable hydrographical change in the northeastern Sea of Japan has been intimately correlated with this variation. From May to July and August, 1938, the *Soyo-Maru* took special surveys in the sea regions above mentioned and recorded the phenomenon.

With regard to Kurosio east of Japan, there are the main current of Kurosio flowing from the sea off Tyosi in an easterly direction in the zone of lat. 36°–37° N with a velocity of 1–2 knots, and a branch separated from the main current and flowing to the north-northeast, nearly following the longitudinal of 144° E.[128] The branch current turns to the east in the zone of 40°–45° N. As it proceeds farther to the east, a greater quantity of the main current is deflected to the south in accord with the divergence of the stream lines, at length entering into the return current along the latitude of about 34° N. Coming to the area east of 180° E, Kurosio becomes too feeble to be recognized distinctly.

Usually the branch current shows three arms, running out in longitudes 144°–145° E, 148°–149° E, and 155°–156°–158° E, and furthermore, from summer to autumn, yet another branch is added, which runs in the sea adjacent to Sanriku, beginning off Kinkazan at longitude 142° E.

The stream lines of Kurosio extend mostly over the area where the water temperature is above 10° C. in winter and above 20° C. in summer. The general character of the currents is similar in all seasons; however, the branch current becomes feeble in winter.

By means of drift-bottle experiments, we are able to detect the south-flowing coastal current along the northeastern part of Japan (of high velocity, about 1 knot, off Same in Aomori Prefecture, and from Hukusima Prefecture to Tiba Prefecture of nearly even velocity, 0.4–0.5 knots) and also the westerly and southwesterly current, having a velocity of about 0.4–0.5 knot in the countercurrent area of Kurosio and the marginal area of the North Equatorial Current.

In the upper layer, above 150 m. depth, in the region west of Erimo Misaki, we observe a distinct appearance of the Tugaru Warm Current flowing out from the Japan Sea. We also recognize, though feebly, the influence of the end of the Soya Current flowing out of the Okhotsk Sea in the coastal region of South Tisima.

Oyasio or Tisima Current.—The name of Oyasio is perhaps given to this current because it is a source of food for the animals and vegetables in the northern sea region. Oyasio[129] flows southwesterly along the waters adjacent to Tisima and Hokkaidô, with a velocity of less than 1 knot (on an average about 0.5 knot), and turns in a southerly direction from the sea off Sanriku to the sea off Hukisuma Prefecture. Thence a branch proceeds farther to the south and, in the sea region off Tyosi at the boundary zone of cold and warm water masses, sinks obliquely toward the south in the intermediate layer as the Oyasio Undercurrent.[130]

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[126] M. Uda, Kwagaku (Science), 7, 9, 10, 1937; K. Koenuma, U. S., 18, 5, 1938.

[127] M. Uda, as cited in note 126.

[128] M. Uda, J. I. F. E. S., 6, 1935; 9, 1938.

[129] Regarding the investigation on Oyasio, the Report of the Hokkaidô Fisheries Experiment Station, S. T. H., is particularly worthy of notice.

We see three conspicuous branches of the Oyasio Cold Current off Sanriku region, commonly found in summer in the vicinity of 141°–143° E, 146°–147° E, and 150°–151° E, respectively. As a general rule, the Soya Current and the Tugaru Current, intermingling with the cold current, flow in the direction sustaining the southerly current.

The independent studies by K. Suda,[131] R. Sigematu,[132] M. Uda,[133] and Y. Nakazima[134] on the origin of Oyasio are almost in accord with the following view, that the major source of Oyasio is to be found in the Okhotsk Sea where plenty of sea ice is produced in winter. After flowing out through the straits in the central part of the Tisima Islands into the Pacific Ocean, it combines with the smaller cold current from the Bering Sea which flows along the east coast of Kamtchatka in a southwesterly direction. Oyasio then flows south or southwest to the sea region near Sanriku with a velocity of 0.5 knot. K. Suda has proved that the water flowing out from the Okhotsk Sea is enough to feed the one branch of the Oyasio near the Japan Islands.

From data obtained by the survey of the *Unyo Maru*, the southerly-flowing current in the central part of the Okhotsk Sea was first inferred by H. Marukawa (1918, 1919);[135] R. Sigematu[136] later computed its velocity dynamically as about 0.3 knot.

Starting from the water mass above the depth of 200 m. in the region of Oyasio water neighboring the boundary adjacent to the water of Kurosio, the water mass belonging to the Oyasio Undercurrent sinks obliquely beneath the water of Kurosio owing its greater density *in situ*.

Since the water mass of the Oyasio Current consists of cold water of low salinity having its origin in the water fed by snow and ice in the upper layer of the northern sea above depths of 25–50 m., and dichotherm water of relatively constant salinity in the lower layer at depths of 50–200 m., sinking of cold water occurs along the surface of discontinuity at two steps corresponding to the polar front and secondary polar front, so called by K. Suda (1936).[137] On those fronts the vortices around the horizontal axis obeying the mechanism pointed out by K. Suda are considered.

M. Uda[138] has indicated the coincidence of the depth of salinity minimum in the intermediate layer and the minotherm depth in the dichotherm layer as proof of the presence of the Oyasio Undercurrent in the vicinity of the line of discontinuity. The southern limit of the dichotherm water (the nucleus of the Oyasio water mass) fluctuates with the increase and decrease of the Oyasio Undercurrent. In winter, Oyasio itself flows along the coast of northeastern Japan most strongly in the surface layer. In late spring and until midsummer, however, it flows southward in the subsurface layer. According to K. Koenuma,[139] the subarctic intermediate water, judging from the thermohaline curve, seems to be predominant in summer in the tropical region of the western Pacific. The water temperature in the intermediate layer beneath the Kurosio is lowest in summer. It seems that the growth of the Oyasio Undercurrent in summer correlates with the strength of the north-going warm current in the upper layer in that season. In short, with the coming of summer the general circulation in the vertical section of the northern sea becomes vigorous, and in autumn decreases, every year.

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[130] M. Uda, J. I. F. E., 3, 1933.

[131] K. Suda, Sangyo Kisyo Tyosa, Rep. Cent. Met. Obs., 4, 1, 1933.

[132] R. Sigematu, S. Y., 12, 8, 1933.

[133] M. Uda, J. I. F. E. S., 9, 1938.

[134] Y. Nakazima, S. T. H., Hokkaidô, 43, 1938.

[135] H. Marukawa, Gyogyo Kihon Tyosa Hokoku, 6, 7, 8, 1918, 1919.

[136] See note 132 above.

[137] K. Suda, Geophys. Mag., 10, 2, 1936.

[138] M. Uda, U. S., 15, 12, 1935; Geophys. Mag., 11, 4, 1938.

[139] K. Koenuma, Mem. Mar. Obs., 6, 3, 4, 1937, 1938.

It is to be noted that the Oyasio Undercurrent descends obliquely to the southern depths carrying the water of rich dissolved oxygen.[140] Influenced by the deflecting force of the earth's rotation, and by the bottom configuration of the Japan Trench, which separates a branch in Sagami Wan at the south of Tiba and east of Hatidyozima and another branch invading the region between Miyake-zima and Hatidyozima, the main branch of the Oyasio Undercurrent goes farther along the Japan Trench and turns to the west at the north of the Ogasawara Islands, at length entering the southern sea basin of Japan. Frequently we see the cold water in the seas off Mie Prefecture, Hyuga Nada, off the east of Ryukyu and Taiwan, and on the east side of the ridge running from Igu to Ogasawara, owing supposedly to the upwelling of the water of the Oyasio Undercurrent.

Currents in the Japan Sea.—Recent investigations of currents in the Japan Sea have been conducted by the surveying ships *Yamato*, *Syunpu-Maru*, *Misago-Maru*, *Soyo-Maru*, and others, and the summarized results have been reported by R. Sigematu,[141] K. Suda,[142] K. Nisida,[143] and M. Uda,[144] respectively.

Southwest of Kyusyu, a branch of Kurosio is separated to the northwest, and coming to the north, again in the sea west of Kyusyu it separates into two parts, one of which, as the Tusima Current, passes through Tusima Strait and flows into the Japan Sea with a velocity of 0.5–1 knot, and the other, as the warm current, flows into the Yellow Sea, proceeding northward in the spring and retiring to the south in autumn with a velocity of 0.1–0.3 knot.

In the Japan Sea the circulation as a whole is counterclockwise, and is subjected principally to the inflow of the Tusima Current and to the countercurrent on the continental side influenced by the deflecting force of the earth's rotation.

Progressing northward with a velocity of about 0.5 knot along the coast of Japan Proper, the main branch of the Tusima Current meets again in the sea region west of Aomori Prefecture with the East Tyosen Warm Current, which has separated at the north of Tusima from the main Tusima Current and flowed toward the north with a velocity of 0.3–1 knot. Afterward two-thirds of the combined warm current flows out from Tugaru Strait to the Pacific side, and the remaining water continues to flow northward, at least the greater part of it flowing out from the Soya Strait into the Okhotsk Sea.

From the coincidence of the result obtained by dynamical computation and that obtained by actual observation, the Tusima Current is approximately inferred as the density current.

The East Tyosen Warm Current is fed mainly by the water passing the strait between Tusima and Husan and transports the water of remarkably low salinity in summer in the upper layer.

The warm and the saline water mass, rotating in a clockwise direction, penetrate deeper into the region centered in the vicinity of Uturyo To.

The main branch of the cold current in the Japan Sea is the North Tyosen

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[140] K. Ito, R. O. W. J., 2, 2, 1930; M. Uda, J. I. F. E. S., 6, 1935.

[141] R. Sigematu, S. Y., 11, 1, 1932.

[142] J. O. Kobe, 1930–1934.

[143] K. Nisida, U. S., 15, 2, 3, 6, 1935.

[144] M. Uda, J. I. F. E. S., 5, 1934; *idem*, R. O. W. J., 6, 1, 1934; *idem*, J. I. F. E. S., 7, 1936.

Cold Current, which begins from the sea off Vladivostok and flows in a southerly direction along the east coast of Tyosen with a velocity of 0.2–0.5 knot. The Liman Cold Current flowing southward along the continental side to the west of Karahuto with a velocity of about 0.3 knot, and the cold current flowing along the coast of Maritime Province with a velocity of 0.3 knot, are distinguished from the North Tyosen Cold Current.

The water mass in the upper layer of the Japan Sea is separated from the water mass belonging to the cold current system on the continental side of Japan Proper by a conspicuous line of discontinuity (a line of convergence off the east coast of Tyosen) running through the central part of the sea.

We find also a countercurrent flowing in southwesterly direction between the Tusima Warm Current and the East Tyosen Warm Current.

Although the general character of the currents in the Japan Sea in autumn, 1933, resembled that of the spring of 1932, in the Yellow Sea and in the northern part of the Japan Sea it showed a marked difference, owing to the growth of the northwest monsoon contrary to the decrease of Tusima Current and its branches in the autumn.

The invasion of the cold water toward the south in the lower layer of the Japan Sea increases in the summer in the trench of Tusima Strait, off Husan, and from spring to summer increases in the sea adjacent to Japan Proper.

The lateral circulation in the Japan Sea has been discussed by K. Suda.[145]

Currents in the Inland Sea and bays.—Surveys in the Seto Naikai (Inland Sea) have been made by the *Syunpu-Maru* of the Imperial Maritime Observatory for more than ten years continuously. From these surveys[146] and from the investigation by M. Uda,[147] who compiled the data reported by the local Fisheries Experimental Station from 1918 to 1930, we distinguish three branches of the warm current system, from Bungo-, Kii-, and Simonoseki Suido.

Plotting the residual currents obtained by means of the Ekman-Merz current meter, K. Hidaka[148] has apparently discovered a weak east-going current in Seto Naikai with a velocity of less than 0.2 knot, though it is obscure in Harima Nada.

On the Japan Proper side of the Japan Sea, in the Wakasa Wan, Toyama Wan, and Isikari Wan, and so on, vertical currents rotating in a clockwise direction induced by the north-going Tusima Current in the offing are observed, accompanied by eddies corresponding to the topographical condition in the bay. In particular, in the Wakasa Wan a special survey was successfully undertaken in July, 1931, by four research vessels (*Soyo-Maru, Tazima-Maru, Syowa-Maru,* and *Hukui-Maru*) by means of current floats and current meter.[149]

On the Pacific side the circulation in Hyuga Nada, Bungo Suido, Tosa Wan, Kii Suido, Kumano Nada, Ise Wan, Suruga Wan, Sagami Wan, Tokyo Wan, and so on, show a counterclockwise rotation generally, which may be aroused by the strong current of Kurosio in the offing as the induced countercurrent corresponding to the topographical configuration and by the action of the deflecting force due to the earth's rotation. In winters from 1929 to 1935, investigations by the *Soyo-Maru* in the Sagami Wan were carried out in detail.[150]

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[145] K. Suda, Geophys. Mag., 10, 2, 1936.

[146] J. O. Kobe, 1, 1, 2; 2, 2, 3; 9, 2, 1936; 10, 1, 1937; 11, 2, 1938.

[147] M. Uda, J. I. F. E. S., 3, 1933.

[148] K. Hidaka, U. S., 17, 2, 1937.

[149] M. Uda, R. O. W. J., 4, 1, 1932.

[150] M. Uda, J. I. F. E. S., 8, 1937.

Special surveys were undertaken by the *Syunpu-Maru* in the bays of Japan successively, that is in the Tokyo Wan,[151] Osaka Wan,[152] Ise Wan,[153] Omura Wan,[154] Mutu Wan,[155] Hunka Wan,[156] Toyama Wan, and Ariake Kai,[157] Yatusiro Kai,[158] and so forth, with descriptions of all the oceanographic elements. In addition to these investigations, the hydrography of Tugaru Strait was also studied by the *Syunpu-Maru.* In the Tokyo Wan, oceanic water flows in along the Tiba Prefecture side, while the coastal water runs out along the coast of Yokohama. In the deep layer of Hunka Wan (Volcanic Bay), the sea water is nearly stagnant (similar to the bottom water in the eastern part of the Mutu Wan), containing only 3 cc/l. of dissolved oxygen, and is rich in nutrient salts.

There should be noted, further, the reports of investigations by S. Yoshimura in the Simoda Wan[159] and Matusima Wan,[160] and by Y. Matue in the Aburatubo Wan,[161] which described the hydrographical features minutely, and the special investigations of M. Okada on the Sagami Wan, and the survey in the Tyosen Kai Wan by the Fisheries Experiment Station of Tyosen, Husan.

Fluctuation of the hydrographical conditions.—Since the hydrographical conditions fluctuate from year to year and show the cyclic change of considerably long periods, the tendency of rise or fall of the water temperature is seen if we look to a part of its trend. After studying the five-year mean of the water temperature along the coast of Japan, observed over a period of thirty to forty years, M. Uda[162] has reported the average change of temperature as less than 1° C. (almost about 0.5° C.) per ten years. On the Pacific side the rise of water temperature is seen in the region north from Iwate Prefecture. It rises remarkably in South Tisima. However, along the coast from Miyagi to Tiba Prefecture the fall is conspicuous, and except for the undetermined tendency along the southern coast of Japan the temperature near Taiwan shows the decline clearly. On the Japan Sea side, except for the rise at Taka Sima, at almost all stations the fall of the water temperature is obvious. Particularly remarkable is the fall along the coast of Tyosen and along the central coast of Japan Proper.

In order to make clear the fluctuation of the hydrographical conditions, it is usual to compute the correlation of the anomalies. K. Suda[163] has studied variation of the hydrographical conditions in the section east of Taiwan, adopting the concept of variability of any oceanographic element $\frac{\theta - \theta_0}{\theta_0}$ (1937, 1938). From inspection of the isovariability curves the variation of the scalar field of Kurosio has been classified into bodily variation and partial variation, which is subdivided into the laminar, the columnar, and the core type. Introducing the concept of the partial water mass specified by the T—S diagram the Kurosio is regarded as a moving belt of a series of the partial water masses. Variability at a section is concluded to consist of two factors, the turbulence effect and the advective effect.

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[151] J. O. Kobe, 3, 1931.

[152] J. O. Kobe, 8, 3, 1935; K. K. I., 29, 1930; J. O. Kobe, 11, 3, 1938.

[153] J. O. Kobe, 5, 1933.

[154] J. O. Kobe, 8, 1, 1935.

[155] J. O. Kobe, 7, 1934.

[156] J. O. Kobe, 6, 1934.

[157] J. O. Kobe, 11, 3, 1938.

[158] J. O. Kobe, 4, 1932; 6, 1934.

[159] S. Yoshimura, Sc. R. T. B. D., 3, 1936.

[160] S. Yoshimura, Proc. Imp. Acad. Tokyo, 13, 1937.

[161] Y. Matue, Suisangakkai Ho, 7, 4, 1938.

[162] M. Uda, U. S., 18, 9, 1938.

[163] K. Suda, Geophys. Mag., 11, 1, 1937; 11, 4, 1938.

Hydrographical fluctuation in the Japan Sea.—Along the sea off Japan Proper G. Okamoto[164] has ascertained the positive correlation between the day water temperature of 15° C. happened and the day temperature of 19° C. happened in 38 days at a fishing ground in Yamaguti Prefecture, and also between the day of temperature 10.8° C. and the day of temperature 8° C. which happened in 22 days at a fishing ground of Akita Prefecture, and consequently found a way to forecast the beginning of the sardine fishing based on the empirical formulas. Afterwards he computed the correlation coefficients of the water temperature in the Tusima Current at the localities from upstream to downstream successively on the data compiled in 1918–1935.[165] As a result, it was proved that the maximum of the positive correlation displaces from upstream to downstream successively and enables one to forecast on the anomaly of water temperature from winter to summer.

As to the forecast on salinity in the Japan Sea, it may be possible on the basis of the movement of highly saline water mass transported by Tusima Current.[166]

Hydrographical fluctuation in the Pacific Ocean.—T. Okada[167] computed the correlation coefficients between the water temperature at Garanpi (Taiwan) in winter, x, the air temperature at Nemuro (Hokkaidô) y, and that at Miyako (Iwate), z, in the following summer: $r_{xy} = +0.61$, $r_{xz} = +0.62$. Also, he computed the correlation coefficients between the water temperature at Garanpi in winter and that at Miyako in the following summer: $r = +0.53$.

Abnormally low water temperature in the Japan Current in winter is positively correlated with the abnormally low temperature in the Oyasio Current. In a year when the water temperature in the Japan Current in winter is abnormally low, it is expected that there will be a cool summer in northern Japan, especially on the east coast of it. It is well known from the researches by I. Seki, Y. Endo, Y. Tuidi, K. Ando, T. Okada, and others, that the abnormally low water temperature of the sea has great influence on the rice crop of northern Japan through the abnormally cool summer.

Recently, K. Suda (1933)[168] has discussed the abnormally low temperature in the northern sea in 1931 corresponding to the poor rice crop of that year. As for the cause of low water temperature, besides the lack of solar radiation, the abundance of the cold current and the lower cold-water mass produced in this winter was noticed.

With regard to the abnormally low water temperature in the year 1934, the reports from the Imperial[169] and the local Fisheries Experimental Station were immediately available, in which Y. Nakazima[170] (the Hokkaidô Fish. Exp. St.) found a negative correlation between the water temperature along the coast of Okhotsk Sea and the interval of drift ice and the rice crop in Hokkaidô.

For the years corresponding to the poor rice crop, K. Suda[171] indicated the remarkably low water temperature in the surface zone of middle latitudes in the Pacific Ocean which has a tendency to persist from the preceding year to the following summer. On the contrary, in the years corresponding to the rich rice crop a remarkable high temperature is observed in this zone.

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[164] M. Uda, G. Okamoto, J. I. F. E. S., 7, 1936.

[165] G. Okamoto, B. J. S. Sc. F., 7, 1, 1938.

[166] M. Uda, J. I. F. E. S., 2, 1934.

[167] T. Okada, Mem. Imp. Mar. Obs., 6, 2, 1936.

[168] K. Suda, Sangyo Kisyo Tyosa, Rep. Cent. Met. Obs., 4, 1, 1933.

[169] M. Uda, Kwagaku (Science), 5, 1, 1935; *idem*, J. I. F. E. S., 9, 1938.

[170] Y. Nakazima, Hokkaidô Fish. Exp. St. Rep., 1934.

[171] K. Suda, Tenki to Kiko, 5, 1, 1938.

M. Uda (1938) has reported that the fluctuation of the hydrographic conditions in the northeastern sea region of Japan shows its geographical maximum in the central part of the sea, which moves to the relatively southern part in spring and to the relatively northern part in summer. The water temperature in winter and that in the following summer are correlated positively. The mean and the lowest water temperature throughout the year are also correlated positively. There are to be noted the abnormal warm water from the south carried by Kurosio, that from the northwest carried by the Tugaru Current, and the abnormal cold water from the north carried by Oyasio. Since the variation of hydrographic conditions is accompanied by the moving line of discontinuity, the maxima of fluctuation of the water temperature for seasonal, yearly, and short-period variation are found on the zone around the line of discontinuity. Averages of the water temperature of the abnormally warm years 1933, 1937, and 1938, the abnormally cold years 1931 and 1934, the comparatively cold year 1935, and the normal year 1936, are shown.

The hydrographical fluctuation in the Inland Sea and the bays.—In the Inland Sea and the bays of Japan, by the vertical convection in winter the temperature and salinity become usually homogeneous through the water column from surface to bottom. When the upper water is warmed by the solar radiation and by the inflow of the warm current in spring, or when the salinity is diluted by the increase of precipitation and by the inflow of the land water in summer, the bottom waters in the northern part of the Yellow Sea and in the Ise Wan remain nearly unchanged with respect to water temperature and salinity.[172] In the central part of the Seto Naikai (Bingo Nada, Harima Nada), though it resembles the regions just named, the mixing due to the strong tidal currents and the increase of inflowing oceanic water affects more or less the rise of temperature and the fall of salinity.

The degree of water temperature in such a bay in that year, compared to that in foregoing years, is almost entirely decided by the temperature in February and March in that year, and the difference in water temperature from that of the preceding year in the same month is carried nearly unchanged from winter to summer.

With respect to the daily variation of currents, besides that due to the meteorological influence at the west entrance of Sagami Wan shown by the measurements of the *Soyo-Maru* in the winter of 1934,[173] the variation with the pace of the fortnightly tidal phase on the basis of the current measurement in the vicinity of Mikomotozima in the summer of 1928 reported by T. Akiyosi should be noticed.[174]

PECULIAR PHENOMENA OF CURRENTS

"Siome" or current rip in the seas and oceans.—A comparatively narrow band which appears on the sea surface with singular ripples and which is commonly accompanied by foams and other drifting bodies of various kinds, is called "Siome" (current rip or *Stromkabbelung*).

T. Kitahara has propounded a theory that fish shoals are concentrated in the vicinity of the line of "Siome," which is the contact zone of two different water masses and the collision line of two oceanic currents.

The periodic pattern in a striped form of columnar vortices by thermal convection shown experimentally by T. Terada[175] has brought an important clue on the mechanism of "Siome."

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[172] M. Uda, Teiti Gyogyo Kai, 33, 1937.

[173] M. Uda, J. I. F. E. S., 8, 1937.

[174] T. Akiyosi, S. Y., 13, 10, 1934.

On the basis of observations and experiments concerning "Siome," M. Uda[176] has discussed the nature of "Siome" in the ocean and lesser seas and has classified it into three kinds: first, "Siome" caused by pure convergence; second, that caused by convergence due to upwelling (divergence); and third, that caused by strong current, so to speak, as an apparent "Siome" (e.g., as seen in the sea region off Tyosio), corresponding to the discontinuity of water masses in the subsurface layer. The characteristics of "Siome" in its developing stages—ripples and breakers, an oily band, noise, etc.—were explained. The distributions of "Siome" in the seas adjacent to Japan are usually found in the region around the line of discontinuity in the water masses and currents. The wavy form of the line of discontinuity which includes "Siome" as one of its characteristics, is correlated with the vorticity around the "Siome," and the vorticity is usually proportional to the degree of discontinuity (i.e., approximately proportional to the gradient of water temperature), corresponding to the fact found by K. Suda,[177] that the turbulence has its maximum value on the polar front. Evaluating rotation and convergence in the Pacific Ocean, in the Japan Sea, in Wakasa Bay, and in Sagami Bay, we have found that the line of discontinuity running through the neutral boundary between the positive and the negative rotations and the distribution of "Siome" usually coincides with the distribution of convergence. The accumulation of drifting bodies associated with "Siome" as an ordinary feature of it is a consequence of convergence. From longitudinal and lateral sections of the surface of discontinuity, it appears that the "Siome" along the line of convergence which has been constructed by the spiral stream lines may be considered as a doublet of positive and negative vortices. It agrees with the fact remarked by S. Fujiwhara,[178] that a "Siome" consists of a chain of vortices as its nucleus in an elongated S-form. The frequent occurrence of "Siome" in relation to bottom configuration, particularly on the margin of the continental shelf, has been discussed. The actual examples of the moving surface of discontinuity, including "Siome" and accompanied hydrographical changes, have also been discussed, and pointed out in the adjacent waters of Japan.

From the observation of "Siome" at the front of invading offshore water, K. Kimura[179] has accounted for the mechanism of interrelation between the strong current and the sudden change of water temperature at lower layers near the northeast coast of Suruga Bay, by the influence of warm surface water descending along the discontinuity surface at "Siome."

"Kyutyo" or "strong current."—In the coastal waters of Japan very violent currents occur temporarily, with a velocity amounting to 1 knot or more, and frequently make it impossible to lift the keddle net, a total loss sometimes resulting. Such a phenomenon is named "Kyutyo" ("strong current") by fishermen in this country. The occurrence of "Kyutyo" in intimate relation to the passage of cyclones was first pointed out by T. Miura[180] and afterward treated by M. Uda.[181]

Recently, from detailed observations on "Kyutyo" during several years, K. Kimura[182] obtained useful results on the characteristics of "Kyutyo" in

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[175] T. Terada, Rep. Aeronaut. Res. Inst., 1927, 1928, 1929.

[176] M. Uda, Geophys. Mag., 9, 4, 1938.

[177] K. Suda, U. S., 15, 1, 1935.

[178] S. Fujiwhara, Quart. Jour. Roy. Met. Soc., 1921.

[179] K. Kimura, B. J. Sc. S. F., 7, 1, 1938.

[180] T. Miura, Teiti Gyogyo Kai, 1, 1927.

[181] M. Uda, J. I. F. I., 23, 3, 1928; *idem,* J. I. F. E. S., 8, 1937.

[182] K. Kimura, B. J. Sc. S. F., 7, 1, 1938.

Suruga Bay and Sagami Bay. The reported rise of temperature (of the order 1°–2° C. in a day) accompanied by "Kyutyo" may be a consequence of the rapid approach to the coast of the frontal boundary between the coastal and the oceanic water. The rise is conspicuous in winter when the ascending temperature gradient from coast to offing is at its greatest for the year. Again, though "Kyutyo" occurs in winter, since the coastal water is scanty the rise of temperature is hardly recognized.

K. Kimura[183] has remarked that the normal occurrence of the temperature rise in Sagami Wan and Suruga Wan falls at three periods of about two months each which differ more or less year by year, namely, from late November to early December, late January to early February, and late March to April (called "Year End," "Winter Strong Current," and "Spring Strong Current," respectively).

The comparatively cold and warm water masses distributed in the oceanic water are transported by the ocean current from upstream to downstream and from offshore to coast. "Kyutyo" transports a train of water masses, owing to comparative difficulty in mingling, and brings a variation rapidly from offing to coast. The ultimate cause of the phenomenon lies in the rapid invasion of the oceanic water aroused by an abrupt meteorological change due to the passage of a cyclone or a line of discontinuity. According to K. Kimura, the Japan Islands, especially in March, are frequented by conspicuous lines of discontinuity, which run from north to south and forward to the east, the movement being accompanied by a strong southerly gale in the southern water off Honsyu. The "Spring Strong Current" seemingly begins to occur a week or ten days after these strong gales in the open sea.

Basing his conclusions on the data of daily observations in 1933, 1934, and 1936 at the Awasima fishing ground, K. Kimura has classified the currents of velocity less than 0.5 knot (weak), of velocity 0.5 knot–1.2 knots (rather strong), and of velocity above 1.5 knots (strong), and has found the phenomenon "Kyutyo" corresponding to the rather strong and strong currents.

The inflow to the coast, as well as the outflow, is seen as an extraordinary phenomenon in the active transition period of the current, and when it occurs, the doubly stratified currents of different directions ("Hutae Zio") are frequently observed in Sagami Wan (near Manaduru, Aziro, Oiso) by the *Soyo-Maru.*[184] When the "Hutae Zio" exists, ascending or descending currents are seen at the boundary or at the end of the water masses, including the coastal line. The descending current indicates a convergence on the sea surface and aggregates the pelagic fishes (such as bonito, skipper, and flying fish) near the line of "Siome." The ascending current arouses upwelling of the lower cold water, which invades the upper warm water, condensing the shoals of fishes such as mackerel, tunny, and squid, in the intermediate optimum layer, and thus bringing a good catch.

As an extreme case, fish frozen by the invasion of cold water float in a half-dead or quite dead state.

SEA WAVES AND SEA ICE

Sea waves.—Remarkable studies of sea waves, based on accurate measurements made by means of Froude's apparatus, together with cinematography and the stereophotographic method, have recently been developed by K. Hidaka and his collaborators,[185] and the measurements have also been conducted by the Hydrographic Department. Sea waves in nature exposed by the stereophotographic camera are never represented by mere sinus or trochoidal form, but by a complicated one resembling a contour map of a mountain range. An analysis of the period for a group wave has been conducted by the method of K. Takahasi.

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[183] K. Kimura, B. J. Sc. S. F., 4, 1, 1935.

[184] M. Uda, J. I. F. E. S., 8, 1937.

[185] K. Hidaka, Mem. Mar. Obs., 6, 4, 1938; *idem,* U. S., 17, 8–10, 1937; 18, 5, 1938; 18, 12, 1938.

K. Takahasi[186] has constructed a new type of self-recording wave meter to set on the coast. For the measurement of ocean waves S. Ogura[187] has shown us the principle of a new practical method, measuring the dip of the wave against the visual horizon. Regarding wind-driven waves and dunes some statistical investigations have been done by T. Otani,[188] M. Nakano,[189] and others, on data reported by commercial vessels and records obtained from the tidal stations.

Earlier an interesting study on dunes was made by T. Terada[190] with the use of Helmholtz' resonator, and a theory was proposed concerning the mechanism of "Uminari" (the noisy sound aroused by a train of dune breaking along the coast owing to the escape of the air rolled in the breaker). The latest study of the roller along the beach was made by H. Hukusima,[191] and the motion of the crest of the wave and also of the substantial water particles were discussed on the basis of actual observations and experiments.

Few observations by the surveying ships such as the *Soyo-Maru* and *Syunpu-Maru*, relate to internal waves, which are usually found in a sea having a discontinuous stratification of different densities. The internal waves having a period of a day and those having a period of 3–5 hours were noted by the survey of the *Osyoro-Maru*[192] in the sea west of Kamtchatka. Also, K. Kimura[193] has described the oscillating variation of water temperature and salinity in the middle layer near the coast of Suruga Wan.

Sea ice.—Owing to the geographical restrictions hitherto obtaining, investigation on sea ice has been very scanty in Japan; but since the year 1934 (the year of the poor rice crop in northern Japan) active official surveys have been begun in the adjacent waters of Tisima and in the Okhotsk Sea. Earlier investigations were made by K. Suda, K. Seki, and T. Taguti[194] on the beginning and disappearing periods of sea ice in the Japan Sea, the Okhotsk Sea, and the Bering Sea. Salinity and plankton contained in sea ice have been studied by K. Suda[195] and Y. Matsudaira,[196] respectively. M. Uda and N. Watanabe[197] have reported on the floe ice in the southern sea of Hokkaidô, with measurement of density and thickness of ice, and so forth.

Quoting the theoretical study on the formation of sea ice by S. Fujiwhara (1910),[198] K. Suda[199] has discussed the formation and melting of sea ice and has computed the coefficients of heat conductivity (K) of sea ice from the increment of its thickness.

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[186] K. Takahasi, U. S., 17, 10, 1937.

[187] T. Akiyosi, S. Y., 16, 5, 1937.

[188] Otani, K. S., 1939.

[189] M. Nakano, K. S. Geophys. Mag., 1939.

[190] T. Terada, K. S., 34, 1915.

[191] H. Hukusima, Riken Iho, 18, 2, 1939.

[192] Suisa Kenkyu Iho, 4, 1934.

[193] K. Kimura, B. J. Sc. S. F., 4, 5, 1936.

[194] K. Suda, K. Seki, T. Taguti, J. O. Kobe, 3, 1931; 4, 1932.

[195] K. Suda, J. O. Kobe, 4, 1, 1932.

[196] Y. Matsudaira, U. S., 13, 1, 1933.

[197] M. Uda, N. Watanabe, Kwagaku (Science), 6, 5, 1936.

[198] S. Fujiwhara, Geophys. Mag., 3, 1910.

[199] K. Suda, U. S., 14, 5, 1934.

TIDES AND SECONDARY UNDULATIONS OF TIDES

Tides.—The book, "The Tides in the Sea Adjacent to Japan" (in English), was compiled by S. Ogura,[200] 1933, and may be considered to be the revised edition of the report made by the same author in 1914.

Papers on accurate analysis of the tides and tidal currents in the seas—Seto Naikai (Inland Sea),[201] Urkt Road,[202] Tugaru Strait,[203] Idu Islands,[204] Mariana Islands,[205] Okhotsk Sea,[206] Yellow Sea,[207] Phok Hai,[208] Pecchili Gulf,[209] and Yokohama Harbor[210]—with the co-tidal and co-range charts, have been prepared by S. Ogura and his collaborators. The later researches are based on dynamical computation of tides by the method of Sterneck-Defant, and the results coincide well with those of actual measurements.

Tidal tables, including tables of tidal harmonic constants[211] (M_2, S_2, K_1, O_1, etc.) by the Darwin method, relating to the coast of Japan are published annually by the Central Meteorological Observatory and the Hydrographic Department. In particular, the Imperial Marine Observatory has published detailed investigations on the tides and tidal currents of the important harbors of Japan: Kobe,[212] Osaka,[213] Nagoya,[214] Mozi,[215] etc.

By the *Syunpu-Maru* the measurements of tidal currents have been carried out in Seto Naikai[216] (Kii Suido, Harima Nada, Bungo Suido, Osaka Wan, etc.), Tokyo Wan, Ise Wan, Ariake Kai, Omura Wan, Mutu Wan,[217] etc. By the *Soyo-Maru* the tidal currents in Sagami Wan[218] have been measured. On the tidal currents in the adjacent seas of Tyosen, K. Nisida[219] carried out the analysis precisely. Tidal currents in the Okhotsk Sea and the waters surrounding the Tisima Islands are hardly known except for the scanty observations by the *Osyoro-Maru,*[220] the *Soyo-Maru,*[221] etc.

Secondary undulations of tides.—In 1908 a report of the secondary undulations of tides was given by K. Honda, T. Terada, D. Isitani, and Y. Yosida,[222] and afterward it became an important classic in oceanography.

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[200] S. Ogura, B. H. D., 7, 1933.

[201] S. Ogura, Tenmon Geppo, 23, 11; *idem,* Toyo Gakugei Zassi, 46, 562, 1930.

[202] S. Ogura, Hydr. Rev., 7, 1, 1930.

[203] S. Ogura, S. Y., 11, 1, 1932.

[204] S. Ogura, Tirigaku Hyoron, 6, 7, 1930.

[205] *Ibid.*

[206] S. Ogura, B. H. E., 7, 1933.

[207] S. Ogura, Jap. J. Ast. Geophys., 14, 1, 1936; S. Ogura, K. Kuribayasi, Y. Sanematu, S. Y., 11, 5, 1932; 12, 2, 1933; 15, 9, 1936.

[208] S. Ogura, S. Y., 15, 4, 5, 1936.

[209] S. Ogura, S. Y., 11, 7, 1932.

[210] Hydro. Dep. Syosi, No. 275, 1933.

[211] K. Hidaka, Mem. Mar. Obs., 3, 4, 1929.

[212] K. Suda, K. K. I., 50, 1932; I. Tuboi, U. S., 18, 2, 1938.

[213] K. Suda, Z. Yasui, K. K. I., 49, 1932; J. O. Kobe, 5, 1, 1933.

[214] J. O. Kobe, 8, 3, 1936.

[215] J. O. Kobe, 1938.

[216] J. O. Kobe, 1, 2, 9.

[217] J. O. Kobe, 7, 1934.

[218] M. Uda, J. I. F. E. S., 8, 1937.

[219] K. Nisida, U. S. A. R. H. O.

[220] K. Suda, Suian Kenkyu Iho, 4, 1934.

[221] M. Uda, J. I. F. E. S., 9, 1938.

[222] K. Honda, T. Terada, *et al.,* J. Col. Sc. Tokyo Imp. Univ., 1908.

K. Hidaka,[223] S. Takaya,[224] and others of the Imperial Marine Observatory have treated the seiche in Osaka Wan mathematically, assuming it as a rectangular or elliptical form, respectively, and have compared the calculated results with those observed. Mainly adopting the integration method of Stokes, K. Hidaka has solved the problems in the sea basin of spindle-shaped, elliptical, and other-shaped seiche. M. Nakano[225] has studied the coupled oscillations in two bays consecutive to each other. Furthermore, he has discussed the variation of depth in the bay due to the influence of the wind and has explained the mechanism whereby the bottom sand stirred up by wind wave is transported by the wind-driven current or compensating bottom current aroused by it, according to the nature and size of the particles, and forms drift sand.[226]

Under the supervision of T. Terada, the relations between sea level and pressure, wind, wave, oceanic current, and precipitation have been investigated by S. Yamaguti statistically.[227]

Similar researches on variation of sea level in relation to meteorological conditions have been conducted by R. Sekiguti,[228] T. Nomitsu,[229] and S. Ogura.[230] With respect to "Tunami" aroused by storm winds and "Tunami" aroused by destructive earthquakes, many studies have recently been made by the members of the Earthquake Research Institute, the Imperial Meteorological Observatory, and the Geophysical Branch of the Imperial University. The luminous phenomena accompanying destructive sea waves ("Tunami") was remarked and first illustrated by T. Terada.[231]

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[223] K. Hidaka, U. S. Mem. Mar. Obs. K. K. I., 1931–1938.

[224] S. Takaya, U. S., 1931–1932.

[225] M. Nakano, Geophys. Mag., 11, 2, 1936.

[226] M. Nakano, Geophys. Mag., 9, 1, 9, 2, 1935; 10, 1, 1936; 10, 3, 1937.

[227] T. Terada, Sc. Pap., 1937, 1938; S. Yamaguti, Bul. Earthq. Res. Inst., 8, 1930.

[228] R. Sekiguti, Geophys. Mag., 6, 2, 1932.

[229] T. Nomitsu, Mem. Col. Sc. Kyoto Imp. Univ., 1932–1937.

[230] S. Ogura, S. Y., 14, 7, 8, 1935.

[231] T. Terada, Proc. Imp. Acad., 9, 8, 1933.

RECENT GAINS IN THEORETICAL OCEANOGRAPHY IN JAPAN

By K. Hidaka

THEORETICAL STUDIES in oceanography have made a marked advance in Japan in these last ten years—an advance attributable, of course, not to the activity of contemporary investigators alone, but also to those of their predecessors. Generally speaking, the subjects treated can roughly be divided into four: (1) ocean currents, (2) the tides, seiches, and ocean waves, (3) *Tunami* and abnormal high water caused by typhoons and winds, and (4) miscellaneous matters. Brief summaries relating to these subjects follow.

OCEAN CURRENTS

In 1927 T. Nomitsu[1] made a study of the properties of the so-called "Grenzfläche" or equipressure layer lying horizontally in the sea and its relation to the currents produced in an ocean in which the density of water varies in the vertical direction.

In 1932 Nomitsu[2] studied the convection currents in a two-layer ocean, and in 1933[3] he wrote a series of notable papers on the drift currents, slope currents, density currents of Ekman's types, and barometric currents, and studied the steady as well as the rising states of these phenomena. He treated these subjects with assumption of various possible surface and bottom conditions, and formulated many useful conclusions on the current models. At almost the same time, K. Hidaka[4] studied the same subjects independently. Though the subjects treated by the two writers are nearly the same, the conclusions obtained are, of course, of independent importance.

In 1935 H. Arakawa and S. Ooma[5] discussed the ocean currents on a rotating globe in analogy to the theory of atmospheric circulation developed by A. Oberbeck, Y. Kodaira, and themselves. He could by this study explain some of the salient characters of the model of ocean currents hitherto considered.

The investigations undertaken by T. Nomitsu and his collaborators were developed very successfully, and in 1934 T. Takegami[6] published an interesting paper on the formation of vertical currents near the boundary which accompanied the water circulation due to the winds. He concluded by these investigations that the vertical current almost vanishes at a distance comparable with the depth of the water from the boundaries. A more rigorous study by numerical process was made recently (1937–38) by K. Hidaka,[7] and the case was solved in which the inertia terms were taken into account in a two-dimensional problem. H. Arakawa[8] treated the similar problem which is posed when the stress of winds is largest at the middle of the canal and gradually vanishes towards both ends.

The coast effects upon drift currents were early considered by Ekman in their steady state. The rising rate was studied by K. Hidaka (1933) and by T. Nomitsu and T. Takegami (1934). Hidaka's conclusions[4] were based on the assumption that the total flow is zero on the coast, even in a rising stage. The theory was improved upon by the other two writers, and more rigorous conclusions were obtained. According to these theories, the surface slope of the sea on the coast instantly reaches a constant value as the wind of constant velocity begins. Nomitsu and Takegami[9] further found that the slope thus formed on the coast then propagates in the sea off the coast with a velocity of nearly $\sqrt{gh}$, where g is the acceleration of gravity and h the depth of the sea. This investigation by Nomitsu and Takegami is very instructive and of importance in the study of the abnormal high water driven by winds.

In connection with the dynamics of stationary and nonstationary ocean currents, we may also cite the studies of K. Hidaka,[10] H. Yamada (1936),[11] Z. Mizawa (1936),[12] D. Syono (1937),[13] and K. Kubota (1938).[14]

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[1] Superior figures refer to footnotes at end of paper.

H. Arakawa[15] undertook a theoretical investigation of conduction in ocean currents.

In 1936 M. Uda[16] studied the distribution of floating bodies in the ocean currents, making use of the results of current measurements by drift bottles thrown in the seas adjacent to this country. The coincidence between theory and observations is satisfactory. In 1934 and 1936 M. Okada[17] published a method of determining the stream lines of ocean currents from observations of temperature, salinity, and other chemical elements.

In 1932 and 1936 K. Suda[18] wrote two papers, following an intensive examination of the current system around the Japan Islands from observational data, concluded that these are mostly of the character of density currents, and discussed the dissipation of energy in them.

Tides, Seiches and Ocean Waves

In 1930 S. Takaya[19] studied the seiches in the Osaka Wan and found that the inclined bed elongates the period of oscillations. The theory was modified by K. Hidaka[20] in 1932.

In 1932 S. Miyahara[21] made a notable study of the tidal problem, his researches being an extension of H. Poincaré's theory, use being made of the integral equations of Fredholm's type.

From 1931 on, K. Hidaka[22] published a series of papers on the free and forced oscillations of water in various types of basins and canals, and obtained successful results for several types of basins with different boundary figures and with different distribution of depth. These papers are still being published, Part XIII being the latest at this writing. One of them deals with the seiches in a channel connecting two seas.[23] H. Arakawa[24] solved in 1933 the case of a circular sea with an island eccentrically placed in it, and M. Kizima[25] the case of a rectangular canal the depth of which varies in accordance with an elliptic law. K. Koenuma[26] tried to solve the problem of seiches in Lake Toya, assuming it to be an annular lake of variable depth.

Seiches in viscous water were attacked by H. Arakawa[27] in 1932, and by K. Hidaka[28] in 1933 and 1935.

K. Sezawa and K. Kanai[29] discussed in 1936 the decay of seiches in straits and bays, considering them as superposed phenomena of progressive waves.

In 1932–33 M. Nakano[30] studied the manner and possible conditions of free oscillations in bays and the "beat" phenomena observed at the mouths of two bays side by side, and the physical connections between the energy of the oscillations and the shapes of a bay. Recently K. Takahasi[31] has made similar studies.

In 1935 T. Nomitsu and K. Habu[32] discussed the oscillations of water on the shelf and explained the various oscillations frequently observed along the coast of the Japanese Empire and on the lake shelves of Lake Biwa.[33] Afterward, K. Hidaka (1935)[34] studied the properties of these phenomena theoretically by the use of Mathieu's functions. In 1935 K. Sezawa[35] explained these phenomena as caused by progressive waves, and paid special attention to their growth and decay.

At the same time, Hidaka[36] also proved the possibility of "bank seiches," or free oscillations due to a submarine bank arising from the bottom of an infinitely wide ocean. However, the practical observations being very difficult, the existence of such phenomena cannot as yet be actually proved. In 1936 Hidaka[37] applied W. Ritz' variation method to solve Chrystal's seiche equation and two-dimensional seiche equation, and the observations of seiches in Loch

Earn, Loch Treig, Lake Yamanaka, Lake Toya, and the Osaka Wan were satisfactorily explained.

At the same time, H. Yamada and S. Adati[38] solved the problem of seiches in Lake Toya, applying the perturbation method frequently used in quantum mechanics.

In 1938 the seiches of Osaka Wan were recalculated by K. Wadati[39] and applied to the explanation of the elevation of water due to winds.[40]

In 1935 I. Tuboi[41] proposed a new method of solving the equations of tides and seiches when the bounding curve of the basin is arbitrarily given in advance. He first transformed the equation into polar coördinates and chose a finite number of points on the bounding curve, and obtained a solution which satisfied the boundary conditions at least at the points above cited. His theory was applied by H. Yamada and S. Adati (1936)[38] for explaining the seiches of Lake Toya, and by K. Hidaka for an oval basin (1938).[42]

K. Hidaka later proposed another idea, replacing the polar coördinates by elliptic coördinates.[43]

In the same year Tuboi[44] also solved the problem of seiches in a lake with rivers pouring in or carrying the lake water away. When one river pours water and another carries it away and a stationary state is reached, the free oscillations go on as if there were no such rivers.

Besides the foregoing we have the contributions of H. Arakawa[45] and S. Sakuraba.[46]

It is the ideal of theoretical investigation under this category that we can find a solution of the oscillations for a given boundary curve and for a given distribution of depth. However, this goal seems far from being attained at present.

The idea of horizontal transfer of momentum is propounded by A. Defant, L. F. Richardson, and D. Proctor, and G. C. Rossby has applied this idea upon the theory of Gulf Stream and Kurosio. The idea was adopted by K. Hidaka[47] in 1938 and the solution was obtained of the horizontal oscillations of water in a bay facing straits and induced by the violent tidal currents prevailing in the straits.

Theoretical investigations on the surface waves of the ocean (wind waves and swells) were made by several persons in our country. In 1932 H. Arakawa[48] showed mathematically that the effect of the atmosphere in damping the ocean waves is quite negligible. In the same year K. Koenuma[49] solved approximately the problem of surface waves, taking the earth's rotation and the viscosity of water into account, several useful results being derived.

The hydrodynamical problem of waves due to an initial disturbance spread over a certain finite extent of free surface, has already been treated by K. Terazawa (1916) for an infinitely deep water. Y. Nomura[50] recently extended the theory to finite depth of water.

RELATION BETWEEN WINDS, PRESSURE, SEA LEVEL, AND TUNAMI

A heavy typhoon (Muroto Typhoon) on September 1, 1934, attacking the central part of Japan, including Osaka, Kyoto, and Kobe, caused serious damages; especially, the city of Osaka was invaded violently by the water of the Osaka Wan (Bay of Osaka) driven by the winds. This disaster only increased the activity of theoretical and practical investigations on these subjects and many papers appeared, dealing particularly with the relations between winds, pressure, and the water level caused by them. Some of these investigations have already been cited in the section of ocean currents, as the coast effect on the drift currents.

In 1935 K. Terada[51] explained the abnormal elevation of the water level, assuming it to be seiches excited by the Muroto Typhoon in the Osaka Wan.

As for the wind effect, we have the investigations by K. Hidaka, G. Nisimura, T. Nomitsu, and T. Takegami. Hidaka[23] propounded in 1933 a theory on the nonstationary relation between the winds and the motion of water caused by them, and applied the results to the case when a temporary gale sweeps on the surface of the sea. In 1935[52] he also studied the forced oscillations of lake water by periodic winds. G. Nisimura[53] treated similar problems in the same year and explained the abnormal water height in Osaka when the heavy typhoon attacked the central part of Japan in 1934.

In the same year T. Nomitsu[54] published a theory of *tunami* and seiches produced by winds and barometric pressure gradient. This author dealt with the problem as relating to different bottom conditions and explained the phenomena observed in connection with the Muroto Typhoon.

In 1936 T. Takegami[55] made a very interesting study on the same subject. He first investigated the deformation of the sea surface and the variation of total flow of water motion generated by a traveling local gale of large scale (e.g., a cyclone). He studied what occurs when the gale travels on an unbounded ocean, or toward or away from a coast in a semi-unbounded ocean. In the same paper he also studied the development of internal long waves along the boundary of a two-layer sea by the impulse of wind on the surface of the sea, as pointed out long ago by Ekman and Sandstrom.

Several authors later treated similar phenomena, the works of T. Hirono (1936)[56] on the Tokyo Wan (Bay of Tokyo) being especially noteworthy.

On the occasion of the 1934 typhoon, Lake Biwa, the greatest lake in Japan, lying in the course of this typhoon, suffered a great agitation of the water surface. These surface fluctuations were studied by T. Nomitsu (1935),[57] R. Takahasi (1935),[58] and others.

As to investigations of the deformation of water surface due to a traveling low pressure, we may cite the investigations of G. Nisimura, H. Arakawa, M. Yositake, T. Inui, and H. Yamada.

G. Nisimura[59] treated the case of a low pressure acting on the surface of a lake and obtained a complete solution to the problem.

H. Arakawa's[60] investigation concerns the case of a low pressure of circular plan traveling on an infinitely wide sea of uniform depth. His investigation is limited to the case when the traveling velocity of cyclone V is smaller than the velocity of propagation $c=\sqrt{gh}$ of the long gravitational waves in a sea of constant depth. If the pressure inside the cyclone be by P lower than outside, the elevation of water inside the cyclone is—$\frac{P}{g\zeta}\left\{1-\left(\frac{V}{c}\right)^2\right\}^{-1/2}$. The deformation of water surface outside is very complicated. At the rear and front sides the water level falls and rises in the directions perpendicular to the course of the cyclone. In 1936 T. Inui[61] developed the theory to the case when V is equal to or larger than c and concluded, after elaborate mathematical treatment, that if $V>c$, the deformation of water loses the symmetric nature it possessed when $V<c$, and the water level rises on the front side and falls on the rear side of the disturbing low pressure and no elevation is seen in the center of the low pressure. In the same year H. Yamada[62] discussed the coast effect on the deformation of water level due to a traveling low pressure and reached many important conclusions. He also discussed the effect of eddy viscosity in avoiding the elevation from becoming large by resonance when $V=c$. In 1938 T. Takegami[63] also treated mathematically the deformation due to a traveling low pressure. By his theory we may conclude that when a low pressure of finite dimension travels from the sea toward the coast with

a velocity $V < c$ we first observe a depression on the coast, and just the reverse if $V > c$. His theory can be applied when the intensity of traveling low pressure varies with time.

Green's Law governing the wave height in a canal of varying section was modified by S. Takaya[64] and H. Arakawa,[65] terms of second order being taken into account.

As for theoretical investigations concerning the *tunami,* or destructive sea waves accompanying submarine earthquakes, we may cite those of T. Matuzawa, G. Nisimura, N. Nakano, I. Tuboi, D. Syono, K. Sezawa, and T. Hirono.

In 1934 T. Matuzawa[66] compared the motion of water due to *tunami* in a V-shaped and a U-shaped bay, and G. Nisimura and K. Kanai[67] made an interesting calculation showing what kind of motion is seen in the interior of the bay if the motion at the mouth is given in advance.

In 1935 M. Nakano and J. Nakagawa[68] made an investigation of the method of tracing the path of propagation of *tunami* caused by submarine earthquakes, provided the positions of the epicenter and the observing station are known, based on the suggestion of the late T. Terada that the path of *tunami* should be determined in such a manner that the time needed for propagation may be a minimum.

In 1935 I. Tuboi[69] drew the fronts of long gravitational waves at successive time intervals on the chart of the Osaka Wan, assuming that the wave velocity is equal to $\sqrt{gh}$ where h is adopted from the chart, and computed the time needed for the *tunami* to propagate in this sea.

In 1935 Syono[70] treated mathematically the waves caused by a sudden deformation of a finite portion of the bottom of a sea of uniform depth. Next year K. Sezawa and K. Kanai[71] showed that there exist a series of prevalent periods in the waves produced by forces acting on a finite area on the sea bottom, and that if C^2 is this area, P the wave length, and h the depth of the sea supposed uniform, the amplitude becomes large, for

$$\frac{h}{P} = 0.5 - 1.0 \text{ if } \frac{c}{h} = \frac{1}{10} \text{ and } \frac{h}{P} = 0.01 \text{ if } \frac{c}{h} = 10.$$

In 1938 T. Hirono[72] showed mathematically that if the wave length of a *tunami* is large compared with the length of channel it travels through, the *tunami* retains a considerable part of its original energy without dissipation, and that since the ordinary *tunami* waves have a sufficiently long wave length compared with the length of the channel between Osaka and the Pacific Ocean, this city is apt to be exposed to serious danger from submarine earthquakes of large scale. This means that in Osaka Wan we can apply the narrow-sea theory for the long waves. Hirono calculated the wave height of *tunami* along the Osaka Wan on this assumption. He then compared the results of calculations with the model experiment of H. Matuo.

Miscellaneous Matters

In 1932 H. Arakawa[73] explained the formation of discontinuity surface of temperature in a lake by assuming that all absorbed solar radiation is used to raise the temperature of the lake water.

In 1935 T. Namekawa[74] pointed out that annual mean temperature of water in the ocean increased from deeper layers toward the surface. This fact cannot, however, be explained by ordinary suffusion equation. On a rather bold assumption, Namekawa was able to explain the observed phenomena fairly well, and added a new term specifying the upward flux of heat due to the spontaneous mixing occurring only in the cooling stage of winter.

In 1935–36 M. Nakano[75] made an extensive investigation on the effect of prevailing winds upon the depth of bays.

In 1936 T. Nomitsu and T. Matsuzaki[76] succeeded in determining the vertical distribution of eddy viscosity in rivers, and showed that usually the coefficient of eddy viscosity is nearly uniform from the surface down to the bed. This theory was applied by H. Higasinaka[77] to the practical determination of eddy viscosity of the Yangtze River in China.

In 1938 S. Hayami[78] proposed a theory of silt transportation by running water, based on the hydrological studies in the Yangtze River, China.

REFERENCES

The list of papers and memoirs referred to in this sketch are given below. The abbreviations used are the following:

ERIB—	Bulletin of the Earthquake Research Institute, Tokyo Imperial University.
Geo. Mag.—	Geophysical Magazine, published by the Central Meteorological Observatory of Japan, Tokyo.
IAP—	Proceedings of the Imperial Academy, Tokyo.
JJAG—	Japanese Journal of Astronomy and Geophysics, published by the National Research Council of Japan, Tokyo.
JO—	Journal of Oceanography, published in the Japanese language by the Imperial Marine Observatory, Kobe.
JSSF—	Bulletin of the Japanese Society of Scientific Fisheries, Tokyo.
JSSI—	Journal of the Shanghai Science Institute, Shanghai, China, Section I.
Kobe Mem.—	Memoirs of the Imperial Marine Observatory, Kobe.
KS—	Kisyo Syusi (Journal of the Meteorological Society of Japan, Tokyo).
Kyoto Mem.—	Memoirs of the College of Sciences, Kyoto Imperial University, Series A.
PMSJ—	Proceedings of the Physico-Mathematical Society of Japan, Tokyo.
Tohoku Report—	The Science Report of Tohoku Imperial University, 1st Series, Sendai.
US—	Umi to Sora (a monthly journal in the Japanese language published by members of the staff of the Imperial Marine Observatory, Kobe.)

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[39] US, 1938.
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[42] IAP, XIV, 1938.
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[48] Geo. Mag., V, 1932 (2 papers).
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[51] KS, 1935.
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THE NETHERLANDS EAST INDIES

Professor E. van Everdingen, chairman of the National Committee on Oceanography for The Netherlands, requested the several members of his committee to prepare material outlining their respective activities. These activities included the preparation and publication of results obtained on the *Snellius* Expedition, a summary of the work of the Hydrographic Survey in The Netherlands East Indian Archipelago, a summary of the marine biological work of the Laboratory for Marine Investigation at Batavia, and gravity observations. Below are given the summaries prepared by Professor van Everdingen's committee, with the exception of the gravity observations made by Professor Vening Meinesz.

OCEANOGRAPHY OF THE PACIFIC

By Commander P. M. van Riel

Observations

In the period 1933–1939 no oceanographic observations were carried out in the Pacific Ocean by Netherlands research ships, but our commercial vessels continued their surface observations.

Publications

As a result of the elaboration of the material obtained during the *Sellius* Expedition, the following oceanographic papers were issued.

VOLUME I. VOYAGE

Chapter I. Program of research and preparation, by P. M. van Riel.

The area of research. Previous investigations. The program. Appointment of the members of the expedition. The trial trip in the North Sea and the English Channel. The voyage to the Netherlands East Indies. List of observations.

Chapter II. The expeditionary ship and naval personnel's share, by F. Pinke and J. P. H. Perks.

The fitting out of the ship. Description of the ship and of the special apparatus. Personnel and duties. Some nautical results. The deep-sea anchoring equipment.

Chapter III. The voyage in the Netherlands East Indies, by P. M. van Riel.

General remarks concerning the research. Weather conditions. The voyage in the eastern part of the Netherlands East Indies. The ship's position at the ordinary and the anchor stations and the observations carried out at each station. Route charts.

Chapter IV. Investigations on shore, by H. Boschma and Ph. H. Kuenen.

A review of the geological and biological researches of the reefs and coasts, with the location thereof.

VOLUME II. OCEANOGRAPHIC RESULTS

Part 2. Soundings and bathymetric charts.

Chapter I. Depth determinations, by F. Pinke.

Wire and echo soundings, apparatus, methods of sounding, sources and magnitudes of errors, corrections. Simultaneous soundings with wire, thermometers, and echo, mean differences, accuracies of the soundings. Velocities of sound. Effect of current on wire soundings. Influence of the bottom slope. Astronomical reckoning and compass bearing, accuracies. Accuracy of the deep sea charts.

Chapter II. The bottom configuration in relation to the flow of the bottom water, by P. M. van Riel.

A historical view of the oceanographic exploration; the construction of the depth charts; a description of the sea bottom and comparison with previous representations; the depths of the various sills which separate the deep basins from each other, in relation to the bottom current; consideration of the properties of the sea water in the basin and that outside the basin in the depth of the sill.

a) A large colored depth chart (in two parts) of the eastern part of the East Indian Archipelago, scale I : 2,500,000 with 16 detail maps.

b) A colored depth chart of the entire Archipelago, scale I : 5,000,000.

Part 3. Die Ergebnisse der Strom- und Serienmessungen auf den Ankerstationen des *Willebrord Sellius,* by L. Lek.

The oceanographic observations, carried out at the anchor stations. All data, tidal constants deducted from surface and subsurface current measurements and from the repeated serial observations of temperature, salinity, and oxygen. The vertical displacement of water layers. Fjeldstad's method of calculation of internal waves.

Part 4. Surface observations, temperature, salinity, and density, by S. W. Visser.

The author discusses in Chapter I the sea surface temperature measurements and in Chapter II those of surface salinity and density. A complete list of the ship's positions and the results of the registrations and measurements concludes his work. Dr. Visser treats the measurements, the corrections applied, the diurnal and annual variations. Four maps contain the isohalines deduced for the four seasons, and the results obtained are compared with those arrived at by Schott and van Weel. The relations between salinity and temperature are considered.

VOLUME III. METEOROLOGICAL OBSERVATIONS

I. Introduction; II. Air pressure; III. Air temperature; IV. Sea-water temperature; V. Relative and absolute humidity, wet-bulb temperature; VI. Wind; VII. State of the sea; VIII. Rainfall; IX. Thunderstorms; X. Clouds; XI. Visibility, radiation, the blue of the sky, halos and coronas; XII. Bibliography.

VOLUME V. GEOLOGICAL RESULTS

Part 1. Geological interpretation of the bathymetrical results, by Ph. H. Kuenen.

A short discussion of the soundings, the chart, and the sections. A regional description of the submarine morphology. The geological conclusions that can be drawn from the new chart (tectonic, structure, submarine faults, the problem of geosynclines, submarine slopes of volcanoes, subaqueous slides, etc.). A discussion of a number of tectonic theories on the development of the East Indian Archipelago (Brouwer, Staub, Wegener, etc.). A summary of the principal results.

The deep-sea charts described for Volume II, Chapter II, should also be consulted with this volume.

Part 2. Geology of coral reefs, by Ph. H. Kuenen.

A description of the investigated coral reefs. The influence of relative changes of the sea level upon the reefs. The phenomena of the reef flat (shingle ramparts, sand cays, beach sandstone, etc.). Views on the formation of atolls. The Toekangbesi atolls, submarine slopes of atolls, position of atolls on the submarine relief, submerged and raised atolls, filling up of lagoons, the glacial fall of sea level, dolomitisation.

VOLUME VI. BIOLOGICAL DATA

I. Introduction; II. The nets and other apparatus for the collecting of biological material; III. The localities; IV. Alphabetical list of the localities.

Koninklijk Nederlandsch Meteorologisch Instituut, nr. 115.—Oceanographic and meteorological observations in the China Seas and in the western part of the North Pacific Ocean, I, II, 1935–1936.

FOURTH PACIFIC SCIENCE CONGRESS

At the Fourth Pacific Science Congress, Batavia, 1929, views were expressed which emphasized the desirability of international coöperation to develop the practical and scientific aspects of oceanography and meteorology. In connection with this principle two atlases have been prepared containing meteorological data charts for the monthly mean conditions of surface current and surface temperature in the area 0°–45° N and 98°–145° E. These values are based on observations from The Netherlands, Great Britain, the United States of America, Germany, France, and other sources.

Observations in the North Sea

Surface.—The ordinary surface temperature and salinity observations on board light-vessels and liners in the southern part of the North Sea were continued.

Subsurface.—When the fisheries cruiser of the Navy was available, subsurface temperature and salinity observations were also carried out in the northern part of the North Sea on cross sections between the Shetland Islands and the Norwegian Coast during the spring or early summer.

Similar observations were carried out occasionally in the fairways near the harbor of den Helder in connection with current and biological observations.

In 1938, hourly current measurements were carried out with improved Carruther's current meters on board the Dutch light-vessels in the southern part of the North Sea. These observations will be continued in the future.

HYDROGRAPHIC SURVEY IN THE NETHERLANDS EAST INDIAN ARCHIPELAGO

By J. Boerema

Surveys

During the last ten years surveys have been executed successively with four vessels until the middle of 1929, with three vessels until the end of 1932, with two vessels until the middle of 1936, with three vessels until the middle of 1938, and until now with four vessels again. Unfavorable economic conditions were the reason for the temporary decrease in the number of survey vessels.

After 1914, by regions, the following broad surveys have been executed (the years of previous surveys of the coast lines concerned have been included):

Sunda Strait.—This strait was surveyed in 1920–1924 (earlier, 1877 and 1883).

West coast of Sumatra.—Vlakke Hook to Siberut Strait, 1915–1920. Rigai Bay-Olehleh, 1924. The intermediate part was surveyed in 1908–1916.

North and east coast of Sumatra.—Sabang, 1923–1924. Olehleh-Belawan Deli, 1923–1927. Roepat-Amphitrite Bay, 1927–1929. The parts between Belawan Deli–Roepat and Amphitrite Bay–Hanka Strait were surveyed in 1890–1891, Banka-Billiton in 1858–1884 (this part as well as Banka Strait has been undergoing revision since 1934), the part Banka Strait–Sunda Strait in 1883–1885 and in 1891.

Revision of Riouw Strait was executed in 1931–1932, of Kidjang Strait (southeast coast of Bintan) in 1932, and some parts of the Palembang River in 1936 and 1938. Later in 1938, the channel south of Bintan was revised, and at present a survey is being made of the Gaspar Straits and the west coast of Billiton.

North coast of Java.—This coast was surveyed in 1883–1890. Since 1914, partial surveys have been executed of the Kangean Islands, the Cape of Indramajoe, and the roads of Panaroekan and Kalianget. Revision has been made of the Cape of Krawang (1935), the Cape of Bobos (roads of Panaroekan 1929), and of the waters off the southeast coast of Madoera (1938).

Bali Strait.—A survey of this strait was executed in 1938.

South coast of Java.—This has been partly surveyed.The survey from Sunda Strait to Genteng Bay was made in 1920 and in 1922–1923; the survey of the channel of Tjilatjap (1885) was revised in 1929 by the former Department of Public Works (now the Department of Traffic and Irrigation).

West coast of Borneo.—After 1914, a revision was made for the estuaries of Ketapang and Paloh rivers. For the rest, the survey of Karimata Strait to the Kleine Kapoeas River was executed in 1880–1884, and from the Kleine Kapoeas River to the north end of the Natoena and Tambilan islands in 1904–1907.

South coast of Borneo.—This coast was surveyed in 1904–1909. The channel in the estuary of the Barito River was revised in 1929.

East coast of Borneo.—A revision was made, after 1914, of the channel near Soewangi (Laoet Strait), Kloempang Bay, Pamoekan Bay, Sangkoelirng Bay, the Beraoe River, and the wads of Lingkas. Moreover, a revision was made of Balikpapan Bay (1929), the estuary of the Koetei River (1931–1932), and the sea in the neighborhood of Boenjoe (1928–1929). Furthermore, a complete survey was made of Laoet Strait with the Borneo Bank in 1890–1896 and from north of Laoet Strait northward to the borders of British Borneo in 1897–1903.

Minor Sunda Islands.—After 1914 a survey was executed near the Paternoster and Postiljon islands from Alor Strait to the east point of Timor, the whole southeast coast of Timor, and the channel to Benoa. In 1929–1930 a revision was made of these bays at the north coast of Bali (St. Nicolaas, Banjoewedang, and Tjloekan Bawang Bay). For the rest these islands were surveyed in 1902–1910.

West and north coast of Celebes.—After 1914 a revision was made of Beling-Beling Bay in 1923, and of the part between the Spermonde Archipelago and Pare-Pare Bay in 1932. The first systematic survey of the Sangir and Talaud islands was executed in 1928–1932. For the rest, the survey of the Spermonde Archipelago dates from 1850, with a revision in 1895–1897, the part of the coast from Pare-Pare to Stroomenpoint from 1899–1901, and the north coast of Celebes from 1898–1900.

East coast of Celebes.—After 1914 a revision was made of the coast between Salabangka Strait and Wowoni Strait; furthermore, in 1926 and 1927 the Banggai and Soela Archipelago was systematically surveyed for the first time. Moreover, the northeast point of Celebes and the Gulf of Tomini were surveyed in 1905–1908, Peleng Strait and Salabangka Strait in 1906–1908, Salabangka Strait and Boeton Strait, 1899–1901.

The Togian Islands, as well as the north coast of the Gulf of Tomini between Tomini and Tilamoeta, were revised in 1929–1930.

South coast of Celebes.—This coast and the islands belonging to it were surveyed in 1900–1904 and 1915–1920, with a revision of the roads of Malili in 1920, of Tana Djampea in 1921, of the wads of Saleyer in 1933, and of the channel to Pomalaä (Bingkoka Bay) in 1937.

Moluccas and New Guinea.—After 1914 the Moluccas and New Guinea were worked energetically. Before that time one systematic survey of a part of the northwest and west coast of New Guinea (around the so-called Vogelkop) was made in 1910–1914, and of the Aroe Islands, where a survey of the east coast was executed in 1893–1894 and that of the west coast in 1909.

The coasts of Halmaheira were charted in 1919–1929, the coasts of Ceram, Boeroe, and Amboina in 1923–1928, the rest of the north coast of New Guinea with the Schouten Islands in 1919–1933, the Sermata and Tanimbar Islands in 1923–1924, and the Key Islands in 1927–1929. In 1929 the estuary of the Digoel River was surveyed.

The southwest coast of New Guinea, south of Etna Bay, and the Arafoera Sea are being surveyed at present.

Summarizing, it is evident that since 1914 special work has been made of the survey of:

a) Sunda Strait, the west coast of Sumatra, the northeast coast of Sumatra.

b) The Sangir and Talaud Islands, the Banggai and Soela Archipelago, the southeast coast of Timor, Boeroe, Ceram, Amboina, Banda, the Sermata, Tanimbar, and Key Islands, Halmaheira, and the north coast of New Guinea with the Schouten Islands.

The surveys of the sea adjacent to the east coast of Sumatra, Banka, Billiton, west coast of Borneo, are being revised, while a survey of the southeast coast of New Guinea has been started.

A new point of the working program has been, in recent years, the towing of a hawser on a determined depth along the principal navigation routes in the Netherlands Indian Archipelago. By this method, the existence of several shallows, till now unknown, has been proved in seas which had already been systematically sounded and charted.

Until now, the following channels have been treated in this way: Riouw Strait (in 1932), Doerian Strait (in 1933), Berhala Strait (in 1933–1934), Kidjang Strait (southeast coast of Bintan in 1933), the channel to Pomalaä (Gulf of Boni in 1937), and the channel south of Bintan (Riouw in 1938).

At the present time Banka Strait and the Gaspar Straits are being surveyed in this way; after these, Karimata Strait will follow.

TIDES AND TIDAL STREAMS

The Royal Magnetic and Meteorological Observatory calculated yearly tide tables of nine places: Soerabaja, East and West Canal, Palembang, Belawan-Deli, Aroe Bay, Barito River (Bandjermasin), Kleine Kapoeas River (Pontianak), Koetei River, and Tjilatjap. These tide tables are published by the Head Office for Navigation.

Furthermore, tide tables are calculated for Tandjong-Priok, Semarang, Cheribon, Beraoe River and Bagan Si Api-Api.

Tables of tidal streams are calculated and published for eleven places on the shipping routes between Malacca Strait and Java Sea and for Sunda Strait.

WATER TEMPERATURES

Observations of sea-surface temperature have been made since 1913 on some specially selected routes in the Archipelago by steamers of the Royal Packet Navigation Company. The routes are: (1) Singapore–Pontianak (West Borneo) (since 1913); (2) Soerabaja–Banjermasin (South Borneo) (since 1913); (3) Bima (Sumbawa)–Makassar (South Celebes) (since 1913); (4) Balikpapan (East Borneo)–Dongala (Central Celebes) (since 1922); (5) Menado (North Celebes)–Ternate (Moluccas) (since 1925).

The observations 1928–1933 have been compiled by Dr. H. P. Berlage, Jr., in Verhandelingen No. 25; those of 1933–1937 by Dr. M. W. F. Schregardus, in Verhandelingen No. 28 of the Royal Magnetic and Meteorological Observatory. The last-mentioned Verhandelingen covers the observations on the routes No. 1 and 3. The observations on the routes No. 2, 4, and 5 were stopped in 1933.

BIOLOGICAL WORK OF THE LABORATORY FOR MARINE INVESTIGATION AT BATAVIA

Marine biological research in the seas of the Malay Archipelago since 1929 was continued principally by the Laboratory for Marine Investigation at Batavia. Because of the distressful times, the field of activity has been considerably limited since the latest report of 1929.

The staff at that time consisted of Professor Dr. H. C. Delsman, head of the Institute, Dr. J. Verwey and Dr. J. D. F. Hardenberg, zoölogists, and Dr. B. Markus, chemist. Dr. J. Verwey went home to Holland in 1931 and was not replaced, nor was Professor Dr. H. C. Delsman when he left in November, 1933; whereas Dr. B. Markus went to the fresh-water fisheries, so that finally Dr. Hardenberg was left as the last and only official. The use of the research vessel was restricted more and more each year until in 1934 it was altogether struck from the budget. Somehow research at sea was managed by means of government vessels so far as the activities of the Admiralty Department were consistent with biological research. The working funds of the laboratory were, of course, much reduced. Delsman continued his investigations about planktonic fish eggs, which have been mentioned in the preceding report, and also started a general survey of the composition and distribution of plankton in the Java Sea. The results of this survey are to be published in 1939.

Verwey, until his departure in 1931, devoted himself to the biology of the coral reefs, especially with respect to the consumption of oxygen and the penetrative power of light, and of the mangrove flora, more especially with respect to crabs. The results were presented in several publications.

Hardenberg studied the occurrence and distribution of different kinds of fish, *Chirocentrus* and *Stolephorus*, meanwhile publishing some systematic work. A profound investigation was instituted regarding the fish fauna and the ecological conditions of the interesting fish region in front of the Rokan estuary in the Straits of Malacca. In connection with this, other estuaries in Sumatra and Borneo were also visited, and investigation was begun which in 1938 could be extended to New Guinea. Special attention was paid on this occasion to the hydrography of those estuaries which have a threshold toward the ocean.

In relation to the reduced and uncertain means of conveyance, the program was altered in 1934, the field of research being chosen nearer home in the Bay of Batavia. It is proposed to compile a list of fauna of the Bay of Batavia, in which all groups will be dealt with. The foraminifera and the mollusca are now practically finished. The different groups are to be treated by different specialists not connected with the Laboratory. Besides this investigation, some attention is being paid to the quality and quantity of the bottom fauna, in order to find out how far this contributes in tropical seas to fish food, as it so noticeably does in colder waters. This work may also be of great importance for the fisheries. The results thus far obtained show great poverty of the bottom. The quantity of living substance found per unit of surface is only a fraction of that of the North Sea; in number of kinds, however, it is much greater.

Towards the middle of 1936, a better time came again for marine investigation. The Institute for Sea Fisheries appointed two biologists, Dr. J. Reuter and Dr. J. Westenberg, who were to work under the direction of the head of the Marine Investigation Laboratory. A common, modern, working program, touching both fisheries and biology, was made up and has been partly carried out. Generally speaking, it comprises, of course, the knowledge of the biology, occurrence, and distribution of economically useful fish in the Java Sea, as also improvements in methods of fishing. This is especially Reuter's concern. For the present he is restricting himself mainly to the decapterus forms and some others as caught by means of so-called fish decoys. Besides the examination of stomach contents, the composition of the plankton is always kept in view. Great attention has, moreover, to be paid to hydrography, for which purpose an oceanographer is to be appointed in 1939 at the Marine Investigation Laboratory. A small vessel will be placed at the disposal of the Laboratory.

Westenberg is to extend the above-mentioned bottom investigation of the Bay of Batavia to the whole of the Java Sea. It is expected that by this means important data may be obtained about the geology of these countries. Westenberg is also studying the different problems regarding the preserving of fish and other marine products. The head of the Marine Investigation Laboratory, in this connection, studied the migration of the decapterus forms. A preliminary publication on these subjects has appeared.

Along the coasts of Java, sea-fish ponds are found over a large area, which administratively belong to fresh-water fisheries. Dr. B. Markus especially examined their bottoms in order to find a connection between the qualities of the silt and the yielding capacity of the ponds and further factors that might rule production.

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PHILIPPINE ISLANDS

Dr. B. M. Gonzalez, chairman of the National Research Council of the Philippines, states that the following subcommittees have been appointed to collaborate with the International Committee on the Oceanography of the Pacific.

1. *Physical and Chemical Oceanography*
    - Dr. Amando Clemente
    - Dr. Jose M. Feliciano
    - Commander F. B. T. Siems
    - Mr. Antonio G. Perez
2. *Marine Biology*
    - Dr. James W. Chapman
    - Mr. Jose S. Domantay
    - Dr. Amado T. Feliciano
    - Dr. Hilario A. Roxas
    - Dr. Artemio V. Manza
3. *Fisheries*
    - Dr. Deogracias V. Villadolid
    - Mr. Florencio Talavera
    - Dr. Silverio M. Cendana
    - Mr. Andres M. Mane
4. *Fisheries Technology*
    - Mr. Heraclio Montalban
    - Mr. Gonzalo G. Ferrer
    - Mr. Agustin Umali

REPORT OF THE COMMITTEE ON OCEANOGRAPHY

By Hilario A. Roxas

At the Fourth Pacific Science Congress, held in May, 1929, in Java, a standing international committee on Oceanography of the Pacific was created. Dr. William H. Brown, then Director of the Bureau of Science, was appointed a member of it, and Dr. Leopoldo A. Faustino a member of the subcommittee on coral reefs. A Philippine Committee on the Oceanography of the Pacific was created on October 3, 1930, with Dr. William H. Brown as chairman, with three subcommittees: one on physical and chemical oceanography, composed of Commander G. H. Hawley, then Director of Coast Surveys, as chairman, and the Rev. Miguel Selga, S.J., as a member; one on fisheries technology, with Mr. Wallace Adams as chairman, and another on coral reefs, with Dr. Faustino as chairman.

On September 10, 1931, a report of the work accomplished by the Philippine Committee was submitted to Dr. T. Wayland Vaughan, Chairman of the International Committee, and this was incorporated in the Proceedings of the Fifth Pacific Science Congress held in Canada in 1934.

On December 12, 1935, Dr. Thomas G. Thompson was appointed Chairman of the International Committee in place of Dr. Vaughan, who tendered his resignation, owing to ill health. At this time the work of the Committee relating to the Philippines was entrusted to Dr. Manuel L. Roxas, then Chairman of the National Research Council.

In January, 1936, as an answer to a query sent to Dr. Roxas by Dr. Thompson, the writer submitted the following memorandum:

1. Outside the work of Dr. Leopoldo A. Faustino on coral reefs of the Philippines and the work of Father Miguel Selga and his associates on certain phases of physical oceanography, no other work on Philippine oceanography has since been reported.

2. Some of the oceanographical subjects about which we have very little information are the following:

a) *Bacteriology.* Marine bacteria and their relation to lime deposits.

b) *Marine fungi.* Their distribution, characteristics, and physical and physiological activities.

c) *Marine plankton.* Qualitative and quantitative study of inshore and deep-sea diatoms, flagellates, crustacea and their larvae, fish eggs, and larval fishes and their distribution and seasonal abundance.

d) *Foraminifera.* Systematic study of foraminifera and their relation to marine bottom deposits, as well as study of their life history.

e) *Biology of fishes.* Life history, embryology, feeding habits, spawning grounds, migration, distribution, reaction to external and internal factors, etc.

f) *Physical oceanography and meteorology.*

g) *Chemical oceanography.* Determination of nutrients such as phosphate, silicate, and nitrogen compounds, as well as oxygen or hydrogen ion concentration of sea water. Study of carbon dioxide, titratable base or alkalinity, and the buffer system in sea water, and of calcium content of sea water.

3. The National Research Council has now available a sufficient number of members and associates who can undertake studies related to these subjects; but without facilities and time, none of the studies can be undertaken. It is known that Father Miguel Selga, who has been most active in physical oceanographical studies, has had to spend his own funds to carry on his work and to publish his results, which none or few of the members of the National Research Council can afford to do. It is therefore recommended that besides obtaining the full and unconditional support of the U. S. Coast and Geodetic Survey, men now in the government service should be especially assigned or detailed by their respective heads to carry on intensive oceanographic studies for some time. Among these may be mentioned the following: Dr. Jose M. Feliciano, Dr. Cornelio C. Cruz, Mr. Ignacio Salcedo, in physical and chemical oceanography; Mr. Porfirio R. Manacop, Dr. Amado T. Feliciano, Dr. Deogracias V. Villadolid, in marine plankton and fish biology; and Dr. Walfrido de Leon and his associates, in bacteriology. Arrangement should be made whereby the above-named workers will be given a working place in the coast-guard cutters of the government. A small room should be fitted in each cutter wherein work may be done during the trips.

4. With the death of Dr. Faustino, a man should be trained to take up the study of corals and coral reefs.

5. The International Association of Physical Oceanography has certain limited funds and its executive committee is prepared to receive applications for grants to assist in the prosecution of researches in physical oceanography as well as to improve mastery of the technique by travel in foreign countries. It is suggested that the National Research Council take advantage of this opportunity. Applications for grants should be addressed to Professor J. Proudman of the University of Liverpool.

6. As all works in oceanography will, in one way or another, help the fishing industry of the Philippines, attempts should be made to secure by special legislation funds for oceanographic studies. If this fails, funds should be secured from foreign institutions like the Educational Board of America or other foundations. It is futile to expect results if the local workers are not given time and facilities to carry on investigations.

As a result of the foregoing memorandum, the following persons were requested to pursue oceanographic studies: Dr. Walfrido de Leon, in marine bacteriology; Dr. Jose M. Feliciano, Dr. Cornelio C. Cruz, and Mr. Ignacio Salcedo, in physical and chemical oceanography; Dr. Deogracias V. Villadolid and Mr. Porfirio R. Manacop, in fish biology and life history; Dr. Hilario A. Roxas and Dr. Amado T. Feliciano, in marine plankton.

On March 30, 1937, under the joint auspices of the National Research Council, the University of the Philippines, and the Bureau of Science, Mr. Jose S. Domantay, Mr. Jose V. Santos, and Mr. Francisco R. Paguirigan, with the extensive aid of the S. S. *Fathomer* of the U. S. Coast and Geodetic Survey, made studies of the west coast of Palawan from April 2 to April 13, 1937. After this brief survey, Mr. Domantay reported on the "Marine Fauna of Ulugan and St. Paul's Bays, Palawan," and Mr. Paguirigan wrote a preliminary report on the "Shoreline and Sea Deposits of Ulugan Bay, St. Paul's Bay, and Subterranean River."

In April, 1937, M/L *Science I* of the Fish and Game Administration was sent to Lingayen Gulf with Mr. Ignacio Salcedo of the University of the Philippines and Mr. Jose S. Domantay for marine studies. As a result of this trip, Mr. Salcedo wrote a report on the "Physical and Chemical Constants of Waters around the Hundred Islands," and Mr. Domantay submitted a preliminary report on the "Marine Fauna along the Western Part of Lingayen Gulf." The above-named papers, together with the paper of Mr. Domantay on "Puerto Galera Marine Biological Station," are included elsewhere in this report.

Investigations in marine biology and fisheries in the Philippines are carried out by certain staff members of the Department of Zoölogy, University of the Philippines, and of the Fish and Game Administration, Bureau of Science. The following list of recently published papers gives an idea of the fishery science of the Philippines:

BLANCO, G. J., and ARRIOLA, F.
1937. Five species of Philippine shrimps of the genus *Penaeus*. Phil. Jour. Sci., 63:227–258.
MANACOP, P. R.
1936. The sexual maturity of some commercial fishes caught in Manila Bay. Phil. Jour. Sci., 59:383–391.
1937*a*. The artificial fertilization of danguit, *Amphacantus oramin* (Block and Schneider). Phil. Jour. Sci., 62:229–237.
1937*b*. The fisheries of Lake Mainit and of northeastern Surigao, including the islands of Dinagat and Siargao. Phil. Jour. Sci., 64:341–357.
MARTIN, C., and MONTALBAN, H. R.
1934. Philippine Sillaginidae. Phil. Jour. Sci., 55:221–229.
1935. Philippine Parapercidae. Phil. Jour. Sci., 56:215–227.
MONTILLA, J. R.
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RASALAN, S. B.
1937. Si-si fishery of Samar, Philippine Islands. Phil. Jour. Sci., 64:269–279.
ROXAS, H. A.
1934*a*. A review of Philippine isospondylous fishes. Phil. Jour. Sci., 55:231–295.
1934*b*. A review of Philippine Mugilidae. Phil. Jour. Sci., 54:393–432.

ROXAS, H. A., and MARTIN, C.
1937. A check list of the fishes recorded from the Philippines. P. I. Dept. Agr. Comm. Tech. Bull. No. 6.
SALCEDO, I. S.
1936. A preliminary study of the physical and chemical properties of the waters of Manila Bay and Puerto Galera Bay. Univ. Phil. Nat. App. Sci. Bull., Vol. 5, No. 2.
UMALI, A. F.
1934. The fishery industries of southwestern Samar. Phil. Jour. Sci., 54:365–392.
1936*a*. Edible fishes of Manila. P. I. Dept. Agr. Comm. Pop. Bull. 6. 562 pp.
1936*b*. Deep-sea fishing in the Philippines. P. I. Dept. Agr. Comm. Pop. Bull. 9. 25 pp.
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1937. The Fisheries of Lake Taal, Pansipit River, and Balayan Bay, Batangas Province, Luzon. Phil. Jour. Sci., 63:191–225.

Furthermore, the staff of the Fish and Game Administration, Bureau of Science, are engaged in the following studies:

Algal Studies with reference to the culture of the milkfish, *Chanos chanos*.
Biology of several sardines and herrings.
Biology of the yellowfin tuna, *Neothunnus macropterus*, and the skipjack, *Katsowonus pelanus*.
Marine protozoa of the Philippines.
Seasonal abundance and vertical distribution of oyster spats.
Sexual maturity of some commercial fishes in Manila Bay.
Survey of fishing banks of the Philippines.

REPORT ON THE MARINE FAUNA OF ULUGAN AND ST. PAUL'S BAYS, PALAWAN

By Jose S. Domantay

Ulugan Bay is a large bay on the western coast of Palawan (lat. 10° 06′ N, long. 118° 46′ E). It is a long bay, with its mouth at the north. From the mouth to the extreme southern cove at Umalagan it measures approximately 8 nautical miles, and its average width is about 3 nautical miles. With the exception of its few coves and inlets of rivers, it can be said to have a regular coast line. Along the eastern side is a large cove, the Tagnipa Inlet, which is almost lined with mangroves, and on the western side are three coves, the largest being Oyster Inlet, locally known as Ulugan Cove, which is apparently rich in marine fauna because of its coral reef bottom. Its depth ranges from 36 to 114 fathoms. Its shallow western shoal is rich in oysters and is regarded as an oyster bed.

The entire bay has a shore line that ranges from muddy, sandy, to rocky, owing to the great number of rivers emptying into it. It has a wide, sandy, rocky shoal along its southeastern side, which is usually exposed at low tide. This shoal, which lies along the Buenavista region, is, like most of its coast line, very poor in marine invertebrates, owing to the absence of coral reefs. The great number of rivers emptying into the bay and the dominance of the algae account for the absence of coral reefs along the coast lines. The few corals that are found surviving from the dominance of the brown algae are species of *Goniastrea*, apparently hardy corals. Near the mouth of the rivers, the sandy, muddy bottom is usually devoid of plants. In places it is grassy, the long eel grasses growing abundantly, with their leaves covered with debris. Along some sandy and rocky bottoms are found brown algae growing luxuriously. There are about fifteen rivers emptying into the bay, excluding many small streams or creeks that usually dry up during the hot season. In rainy days the water along the coast becomes turbid. This perhaps explains the absence of alcyonarians and stony corals along the coast. Corals, however, are found in the deeper parts of the bay several fathoms deep.

St. Paul's Bay is hardly half the size of Ulugan Bay, and lies farther north. Like Ulugan Bay, it is surrounded by hills and mountains. It has a single wide mouth, at its western side, and several small, slightly indented coves. The shore line is alternately rocky and sandy, rocky at the points which separate the small coves from one another. The nature of the bottom of this bay differs from that of Ulugan Bay, owing to the few rivers that empty into it. There are only two small rivers emptying into the bay, with a few creeks or streams that usually dry up during the hot season. The subterranean "mystic river" does not empty directly into it, being checked by a sand bar.

Along the eastern side of the bay is a wide, sandy, rocky to purely rocky shoal, slightly deeper along the shore, so that at low tide it forms a wide, shallow lagoon. The elevated part of this rocky shoal, which separates the shallow lagoons from the deeper part of the bay, is rocky bed covered with brown algae. Farther south is a highly rocky coast line composed of large eroded boulders which are always exposed except at the highest tides. Beyond this rocky region is a small coral reef region, about two fathoms deep, but almost dominated by the brown algae. In some regions along the southern and southwestern side of the bay the shore line is rocky and slopes more abruptly.

Marine fauna of Ulugan Bay.—In general, the marine invertebrate fauna of Ulugan Bay is very poor. The sandy region of the shallow shoal along the Buenavista region is very rich in different types of foraminifera shells. The sponges are represented by about five different genera, namely, *Euspongia,* *Tethyopsis*, *Renicra*, *Siphonocalina*, and *Suberites*. The most common form of sponge is the commercial form, the *Euspongia officinalis*. This, however, is of poor quality because of the presence of much sand and tiny gravels inside the numerous pores. It is said that commercial sponges of good quality are found in the deeper parts of the bay. The coelenterate is poorly represented along the littoral region. A species of *Mastigias* collected from the shoal is apparently rare, too. The only representative of the *Madreporarian* in this region is a species of *Goniastrea* which is not very common. Although not a single Alcyonarian was found from the wide shoal, black precious corals are obtained occasionally by diving in the deeper parts of the bay. Flatworms and roundworms are not represented. Few annelids were seen among the eroded, worn-out rocks. A single species of *Sipunculus* was obtained from under a rock.

The arthropods are represented by different forms of crustaceans. Among the lower forms, except for those found in the plankton which has not been worked out, is a species of *Ibla*, a cirripedian. *Ibla* is usually found attached to crevices or between eroded layers of rocks. Among the higher forms are representatives of the Decapoda and Stomatopoda. The former is represented by several genera of crabs, mostly of *Neptunus*, *Matuta*, *Calappa*, and *Myctiris*; the spiny lobster, *Palinurus*; and the hermit crab, *Pagurus*. The Stomatopoda are represented by different species of *Squilla*. *Neptunus*, *Matuta*, *Calappa*, together with the *Squilla*, are usually found along the partly eroded rocky bottom of the shoal. *Myctiris* is always found along sandy flats which are exposed at low tide. This genus is represented by one species, *Myctiris longicarpus*, which usually appears in groups of countless individuals that move about like diminutive armies headed in the same general direction and moving forward as a unit. Along their way the sand is scooped and scattered in the form of granular files over the smooth, sandy flat. One remarkable behavior of these tiny crabs is the rapidity with which they disappear, escaping into their tiny holes when disturbed. *Palinurus* is usually found in the deeper part along the rocky bottom; *Pagurus*, along the tide mark.

The Echinoderms are poorly represented. Not a single starfish was seen. The ophiuroids are represented by a species of *Ophiocoma scolopendrina* which is found along the partly eroded rocky bottom of the shoal. Another form, the *Ophioplocus imbricatus*, was collected from under rocks. The echinoidea is represented by a few skeletons of the sand dollar, a species of *Laganum*, which were found along the sandy shore. Not a single sea urchin was seen. The holothuroids are represented by three species of *Holothuria*, namely, *H. atra*, *H. pulla*, and *H. impatiens*, and a species of *Polycheria*. The first of these is found exposed along the sandy rocky shoal, and the last three are usually found under rocks and stones. It is also expected that *Actinopyga echinites* and *A. manuritiana* are to be found in the deeper part among coral reefs, because some fishermen used to dive for them, on calm days, for the market. The part of the bay apparently rich in these edible holothurians is Oyster Inlet or Ulugan Cove. Very few crinoids were seen in the deeper parts of the bay and not a single one was collected.

The mollusks are represented by several forms of gastropods and few pelecypods. Most of the larger forms are found in the deeper parts of the bay. The collection of a few live ones, together with shells that have been cast ashore, show the presence of species of the following genera: *Acmea, Arca, Astralium, Calliostoma, Conus, Columbella, Cassis, Cyprea, Drupa, Fasciolaria, Haliotes, Mactra, Natica, Neretina, Nerite, Oliva, Pholas, Purpura, Ricinula, Strombus, Pterocera, Turbo, Turitella, Trochus, Tridacna, Teredo, Vasum.* Oysters are found in some restricted coves of the bay like Oyster Inlet or Ulugan Cove.

The marine fauna of St. Paul's Bay.—The marine fauna of St. Paul's Bay, although richer, resembles that of Ulugan Bay to some extent. All the sponges found at Ulugan Bay, and an additional one, *Donatia,* a silicious type, were found in this bay. The commercial sponges (Euspongia) found at this place are of better quality. These are confined to the shallow lagoon of the sandy, rocky shoal along the eastern side of St. Paul's Bay, where they are not totally exposed at low tide.

The coelenterate fauna of the two bays are almost the same. In spite of the smaller number of rivers emptying into this bay, not a single alcyonarian was found, and the coral reef is generally located in the deeper part. The absence of coral reefs along the shoal is explained by the abundance of algae which tend to deter their growth. No flat or round worms were found, and only a few annelids were seen among the eroded rocks.

The echinoderm fauna is more varied than that of Ulugan Bay. The starfish is represented by two species of *Asterina.* Three species of Ophiuroids (brittle stars) were also found, namely, *Ophiocoma scolopendrina, Ophiocoma erinaceus,* and *Ophioplocus imbricatus.* Echinoidea are represented by a species of *Laganum* similar to the one found in the other bay. The holothuroidea of the two bays are almost the same, represented by three species of *Holothuria,* namely, *H. atra, H. pulla,* and *H. impatiens.* The genus *Polycheria* is not found in this bay. *H. impatiens* is always found under rocks. No crinoids were collected, for they are apparently found in the deeper parts among corals.

The crustacean fauna of the place is almost the same as that of Ulugan Bay. The only one not seen here is *Myctiris longicarpus,* but this is compensated by the presence of a certain species of *Ocypoda* which usually lives along the high-tide mark, where numerous holes are formed which serve as their abode.

The molluscan fauna of the place is also similar to that of Ulugan Bay, with some additional forms not encountered there. The additional forms are representatives of *Avicula, Bulla,* and *Acanthopleura,* together with three species of oysters.

The lower chordate fauna of St. Paul's Bay is richer than that of Ulugan Bay. Many forms of colonial tunicates are found attached to stones. They are usually seen after pieces of rocks are raised. In both places, not a single individual of the large tunicate, the *Pandocia,* was seen; but along the rocky coast lines are the climbing fishes of the genus *Periopthalmus.* Along the fine sandy beach at the low-tide mark are numerous small, long, and narrow flatfishes which bury themselves under sand as the waves break out. When approached, they wriggle fast and follow the water to the deeper parts. Their movement is very peculiar and very interesting. The largest one seen and, accidentally, caught, was about six inches long. It happened to be carried by a strong wave and was stranded above the high-tide mark on dry sand so it could not go back to the water. This form was not seen in Ulugan Bay. Another species of flatfish caught buried in the sand from the Buenavista shoal of Ulugan Bay is thicker, broader, and shorter, and with large white spots. In both places schools of fishes are often seen. Because of the absence of coral reefs along the shallow parts and the sandy nature of the bottom of the different coves, both bays offer good fishing grounds.

The subterranean "mystic river" and its fauna.—A party of fourteen members with two outboard boats entered a subterranean "mystic river" at the southern part of St. Paul's Bay. This river is under a long range of mountains, where also is found St. Paul's Dome, so called because of its hemispherical summit. The river does not empty freely into the sea, as it is obstructed by the presence of a sand bar, and its current is too weak to make headway against the obstacle. The river is very long, with several side branches. Inside the cave, nature displays its beauty in natural and wonderful architectural forms. The water is very clear and apparently with very few fauna, blind fishes. The only animal found inside is the little bat, which exists in very large numbers. At the mouth of the river is a lagoon where animal life is found: Fishes, shrimps, and even crocodiles.

Possibilities of Ulugan and St. Paul's Bays as commercial sponge-fishing grounds.—From the large number of commercial sponges seen along the shoals up to the shore line in the two bays, it may be supposed that the deeper parts of the bay have a greater number of them. It has been said that Moros and other fishermen usually dive for them. Judging from the size of the two bays, the prospects for sponge fishing are good, especially if scientific methods are used in their cultivation.

REPORT ON THE MARINE FAUNA OF THE WESTERN PART OF LINGAYEN GULF

By JOSE S. DOMANTAY

THE HUNDRED ISLANDS AND ITS MARINE FAUNA

THE HUNDRED ISLANDS is a group of many islets ranging from a small rock to an area of a few hectares in size. It is estimated that there are more than a hundred islets in all, the largest having an area of about five hectares. This group of islets is believed to be a continuation of a submerged range of mountains from the mainland. The entire group is apparently divided into subgroups which are separated by channels. The first subgroup is composed of several islets near the mainland. The second subgroup is composed of many islets, including the larger ones. These are separated from the first subgroup by a narrow channel from 6 to 11 fathoms deep. The third subgroup is composed of many islets exposed toward the open part of the gulf. They are separated from the second subgroup by a narrow channel of from 5 to 10 fathoms deep. In between the islets of the three subgroups are shallow passages. In the first subgroup the shallow passages between the islets are muddy. In the second subgroup the passages and neighborhoods of the different islets are either sandy-grassy, rocky, or coral reef. In the third subgroup are found mostly coral reefs and sandy beaches connecting some of the islets. Some appear, at high tide, to be floating, and others, at low tide, resemble mushrooms because of the excavation of their tide mark by wave erosion.

In the first subgroup of islets near the mainland are found different species of crabs and gastropods within the crevices of the wave-eroded tide mark of the different islets. In the sandy-muddy bottom along the shallow passages are observed the *Arca,* a bivalve, and the *Archaster typicus* and *Laganum laganum,* a starfish and a sand dollar, respectively, which are common in the shallow sandy-muddy region of the Lucap Bay, a neighboring place. The pelagic forms found are species of poisonous and nonpoisonous jellyfishes. The former is a species of *Chiropsalmus* with very long tentacles and is supposed to have powerful and dreadful nematocysts. The latter is a species of *Mastigias* and *Aurelia. Cassiopea* may also be found in this kind of habitat because of its presence in some neighboring places within the gulf.

In the second subgroup of islets are found more varied forms of marine fauna. Attached to the crevices of the wave-eroded tide mark of most islets are different species of *Acanthopleura,* a chiton; *Acmea, Neretina, Nerita,* and other mollusks. Below the low-tide mark within crevices are *Echinometra oblonga* and most probably *Echinometra picta,* because the two species are usually found in the same kind of habitat. A small species of *Ophiocoma,* a brittle star, is also found abundantly with only its arms exposed from small holes along and below the low-tide mark. Different species of crabs are found inhabiting the deeper holes and crevices above the low-tide mark.

In the deeper water around these islets, more exposed to the open part of the gulf, are coral reefs wth different species of both solitary and colonial stony corals. Soft corals in the form of different species of *Sarcophyton* and *Lobophyton* are found. *Isis hippuris* and a species of *Telesto* are also found. It is said that species of *Antipathes,* the black precious corals, are found in the deeper parts. Among all these corals are found large sea anemones, which usually harbor a commensal fish, the *Amphiprion.* The echinoderm found among the corals are the *Echinaster luzonicus* and a species of *Nardoa.* Some forms of *Crinoids* are also found. The poisonous sea urchin, *Diadema setosum,* is common. Other forms of sea urchins are likely to be found in the neighborhood, as indicated by some skeletons or tests that are occasionally found cast ashore among piles of dead corals along some beaches. The tests encountered apparently belong to the genera of *Tripneustes* and *Echinotrix*. Skeletons of large spiny crabs and the spiny lobster of the genus *Palinurus* are also found among piles of dead coral fragments. Together with them are different shells of gastropods and bivalves representing different species of *Acmea, Arca, Cyorea, Conus, Cassis, Murex, Ostrea, Pterocera, Tridacna, Trochus, Turbo,* and several others. Along the low-tide mark are countless numbers of small species of hermit crabs apparently of the family *Paguridae*. The climbing fish, *Periopthalmus,* is abundant.

In the sandy-rocky and sandy-grassy regions are found some species of holothurians. The most common is *Holothuria atra*. Some other species like *H. pulla* and *Stichopus chloronotus* are occasionally found. Other species of holothurians may be expected to be found after further survey.

The pelagic forms found are some species of coelenterates. The poisonous and the nonpoisonous jelly fishes found in the first group of islets are also found in the neighborhood of the second group of islets. The pelagic colonial coelenterate in the form of the Portuguese man-of-war, a species of *Physalia,* is found common in some places among this subgroup of islets.

The third subgroup of islets, which is the most exposed region of the Hundred Islands, has a bigger area of coral reefs in its neighborhood. Some shallow coral reef shoals are found connecting two or more islets. In these coral reefs are found forms of marine fauna similar to those encountered in the second subgroup of islets. In addition to them are species of *Ibla,* a barnacle found attached to rocks, and species of *Comengia,* a small bivalve buried along the low-tide mark of fine sandy beaches. The absence of any member of the family *Xenidae* is very striking in these groups of islets. Possibly some of them and other forms of marine invertebrates may be found later on after a more thorough survey of the place.

LUCAP BAY AND ITS FAUNA

Lucap Bay is a large bay southwest of the Hundred Islands. It has an extensive shallow shoal, muddy at its eastern and southern part, rocky at its southwestern part, partly coral reef at its western part, and muddy-sandy to sandy-grassy at the middle part. Unfortunately, all the corals found along its coral reef region were used to fill up the pier and road that have been constructed lately at the bay, and the marine fauna associated with the reef was destroyed with the removal of the corals. The entire shoal is almost exposed at low tide. The entire bay has not been fully surveyed because of its extensive size. Along its eroded rocky and partly muddy shore line are found different species of crabs, hermit crabs, and mollusks. Among the crabs the *Oca* and *Neptunus* are the most common. The hermit crabs are species of the genus *Pagurus*. The mollusks are represented mostly by small gastropods and a few bivalves such as the *Arca* and oyster. Along its muddy-sandy and sandy-grassy regions are found in large number the poisonous and nonpoisonous jellyfishes already observed in the Hundred Islands, and *Archaster typicus* and *Laganum laganum*. Toward the deeper part and along the destroyed coral reef regions are different species of holothurians, *H. atra, H. pulla,* and other species. Species of *Oreaster,* together with some sea urchins of the poisonous type, *Diadema setosum,* and other forms of marine invertebrates are likely to be found, as they are common in the neighborhood toward the north.

THE CAROT SHOAL AND ITS FAUNA

The Carot Shoal is an extensive shallow shoal in the northern part of Cabarruyan Island. It is almost exposed at low tide. The deeper part of the shoal toward the channel is a coral reef region and becomes sandy, sandy-grassy, and muddy toward the shore. In the coral reef region are different species of stony corals and soft corals. It is said that in the deeper parts are found in abundance precious black corals. In the sandy part away from the coral reef are a few corals sparsely scattered together with many species of *Clavularia* growing on pieces of rock and dead corals. One variety of *Culcita novae-guinea* is found. The poisonous sea urchin, *Diadema setosum,* is common. Three species of holothurians were encountered, namely, *Holothuria atra, H. pulla,* and *H. marmorata.* Some species of sponges of the genera *Siphonochalina, Tethyopsis, Suberites, Reniera, Donatia,* and several others are common. In the sandy-muddy and grassy regions of the shoal are found in great numbers *Oreaster nodosus, Archaster typicus,* and *Laganum laganum.* Among the pelagic forms are the poisonous and nonpoisonous jellyfishes already mentioned as occurring in other places of the gulf. In the muddy regions toward the shore are found abundantly species of the genus *Arca,* a bivalve buried in the muddy bottom. Other mollusks, mostly gastropods, are also found, and below the low-tide mark are different species of crabs, hermit crabs, and the climbing fish, *Periopthalmus.* Along the sandy beach are found cast ashore shells of few gastropods and bivalves like oyster, *Arca* and other clams, and skeletons of large cuttlefish.

In spite of the short time spent in surveying this shoal under rather unfavorable conditions when the tide was not very low, and when it was windy and the water not calm, without any water glass to use to look into the bottom, the result of the investigation was nevertheless very encouraging. It is expected that under better conditions and with more adequate facilities to use, many other forms of marine fauna will be found. Different forms of green and brown algae were also observed together with the different forms of marine fauna.

In the neighborhood of this shoal are several more extensive shoals which have not yet been investigated. On the eastern side of Cabarruyan Island are two extensive shoals, mostly of coral reefs. One of these shoals extends from Carot Point to Tondul Point beyond Cangaluyan and Tanduyong islands. The other one is from Tondul Point to Batiarao Point beyond the Panacalan Island toward Lucap Bay. Another very extensive shoal is found along the eastern and northwestern side of Santiago Island from Siapar Point almost to Binabalian Point. The northern part, around Silaqui Island, is bare at low tide. Other extensive shoals which are bare at low tide are found at the eastern side of Bolinao along the Palingasay Point and Cape Bolinao. Several other shallow shoals are found between the Santiago, Siapar, Narra, and Cabarruyan islands, and the mainland from Riripayan Point to Caquiputan Strait. It is said that in all these coral reef shoals, varied forms of marine fauna are to be found. It is also said that in the deeper regions along those neighborhoods are found plenty of pearl oysters and precious black and red corals. The different shallow coral reef shoals mentioned are worth investigating and will no doubt offer a very rich ground for study.

THE PORT OF SUAL AND ITS FAUNA

The port of Sual is a cove or small bay within Lingayen Gulf, in its southern part. The cove is enclosed by hills and mountains from Mangas Point to Portuguese Point, which, were it not for Agno River and a tributary directly emptying into it, would be an ideal place to find varied forms of marine fauna, as in Puerto Galera Bay of Mindoro.

Inside the cove are extensive, low, sandy-muddy beaches and a rocky coast line. In general, the coast line has an alternation of rocky, pebbles, sandy,

sandy-muddy, and grassy to muddy bottoms. Because of the nearness of the mouth of the Agno River and a tributary directly emptying into this cove with some other smaller streams or creeks leading into it, the littoral marine fauna is very poor. Along the rocky region are found few mollusks and crabs. In the sandy-muddy and grassy regions are found two forms of jellyfishes, of the species *Cassiopes* and *Mastigias*. It is said that on rainy days poisonous jelly fishes are abundant. In the sandy beaches along its low-tide mark are numerous hermit crabs, mostly of the *Pagurus* type, and other small species of crabs. One species of *Polyclad,* a flatworm, was found in a sandy-rocky region. A certain species of rare green alga is found dominant along its entire coast line. In the deeper part of the cove are a few corals. These corals, however, will not remain long, because of the muddy bottom of the cove due to the continuous deposition of silt by the Agno River.

Between Sual Cove and the Hundred Islands is an irregular coast line with shallow, rocky shoals. These places, unfortunately, were not investigated, though it has been learned from reliable sources that in Cabalitian Bay are found pearl oysters and the precious red coral. Big octopi are also said to be common in these places.

REMARKS AND RECOMMENDATIONS

It would be advisable to investigate the many extensive shallow coral reef shoals which have not been explored. It may be expected that from Bolinao to Cabalitian Bay are varied forms of marine fauna, as indicated by the rich collections made from some representative places between the two regions. The extensive and varied coast lines and shallow coral reef shoals will offer a rich collecting ground for a marine biological station. If another marine biological station is to be established, the best site will be on Alo Island, in the western part of Lucap Bay. The nearness and accessibility of this island to the Lucap pier, its moderate size, and ideal location, being surrounded by extensive shallow shoals from muddy to coral reef, make it an ideal site. It is situated midway between Bolinao and Cabalitian Bay. With a motor boat all places between the two regions can be easily reached. Besides, the owner of the island, who is a former justice of the peace and a civic-spirited citizen, has voluntarily offered it for the use of any kind of marine government station, biological, fishery, or the like. The island has not been surveyed by the writer, but he has learned from reliable sources that fresh water, which is the disadvantage in the Hundred Islands, can be easily obtained in the place from wells. An artesian well can easily be bored, the place not being rocky, as is evidenced by the extensive cultivation it has undergone.

PRELIMINARY REPORT ON OCEANOGRAPHIC STUDIES

By Francisco R. Paguirigan

In connection with the work of the National Research Council of the Philippines relative to the oceanographic studies that took place along the west coast of Palawan from April 2, 1937, to April 13, 1937, with the help of the Coast and Geodetic Survey, I have the honor to submit in outline form the result of the study undertaken with reference to shore lines and sea deposits.

ULUGAN BAY

Area in square statute miles	24.0
Length in statute miles	8.0
Width in statute miles	3.0
Average depth in fathoms	25.0
Deepest in fathoms	33.0
Longitude	118° 40′ E
Latitude	10° 10′ N

The shore line of the bay within is characterized by the presence of sandy beaches partly or almost covered up by mangroves, varying in length from 300 to 600 meters. The shore line of the southern and northern mouths of the bay is rocky, owing to its immediate exposure to the sea.

ST. PAUL'S BAY

Area in square statute miles	21.0
Length in statute miles	7.0
Width in statute miles	3.0
Average depth in fathoms	20.0
Deepest in fathoms	30.0
Longitude	118° 45′ E
Latitude	10° 12′ N

The shore line of this bay is generally rocky at prominent points, with a few straps and bights of sandy beaches which vary from 300 to 600 meters in length. The general characteristic of the shore line is due to the open exposure of the entire bay to the sea, with the exception of a few bights and coves.

THE SUBTERRANEAN RIVER

Longitude	119° 00′ E
Latitude	10° 10′ N

"In 1910 Dr. Paul C. Freer made a trip to St. Paul's Bay where he, with others, made a study of a remarkable cave, with a subterranean river which empties into the bay. It is possible to run a launch up this river for several kilometers. Freer collected specimens of the limestone in this cave and secured also some excellent photographs which showed evidences of recent uplift along the coast. I examined the limestones in this section, and found that they contain *Lepidocyclina* and *Lithothamnium,* which would place this formation in the upper Miocene."

On board the S. S. *Fathomer* practical study of hydrographic and oceanographic principles is in progress.

A continuation of the work of Salcedo and Clemente has been in progress, and the results of this work will be reported elsewhere in the proceedings of this Congress.

BOTTOM SPECIMENS OR SHALLOW-WATER DEPOSITS SAMPLED BY VERTICAL CAST

Sample	Date	Longitude	Latitude	Depth
Sample No. 1.....	April 2, 1937	118° 47′.6 E	10° 13′.1 N	42.2 fathoms
Sample No. 2.....	April 2, 1937	118° 47′ E	10° 17′.8 N	33.5 fathoms
Sample No. 1.....	April 3, 1937	118° 47′.7 E	10° 11′.9 N	35.0 fathoms
Sample No. 2.....	April 3, 1937	118° 00′ E	10° 00′ N	22.0 fathoms
Sample No. 1.....	April 4, 1937	118° 00′ E	10° 00′ N	24.0 fathoms
Sample No. 2.....	April 4, 1937	118° 48′.3 E	10° 09′.8 N	11.0 fathoms
Only one sample...	April 5, 1937	118° 00′ E	10° 00′ N	38.4 fathoms
Sample No. 1.....	April 6, 1937	118° 48′.9 E	10° 12′.8 N	29.3 fathoms
Sample No. 2.....	April 6, 1937	118° 46′.7 E	10° 10′.3 N	35.4 fathoms
Sample No. 1.....	April 7, 1937	118° 47′.1 E	10° 40′.1 N	56.9 fathoms
Sample No. 2.....	April 7, 1937	118° 46′.9 E	10° 11′.5 N	37.0 fathoms
Sample No. 1.....	April 8, 1937	118° 48′ E	10° 08′.4 N	23.2 fathoms
Sample No. 2.....	April 8, 1937	118° 47′.7 E	10° 36′ N	23.0 fathoms
Only one sample...	April 9, 1937	118° 45′.82 E	10° 44′.9 N	15.4 fathoms
Only one sample...	April 10, 1937	118° 00′ E	10° 00′ N	44.6 fathoms
Only one sample...	April 11, 1937	118° 48′ E	10° 24′.5 N	27.6 fathoms
Sample No. 1.....	April 12, 1937	118° 46′.8 E	10° 08′.6 N	29.7 fathoms
Sample No. 2.....	April 12, 1937	118° 45′.9 E	10° 10′.2 N	29.7 fathoms
Only one sample...	April 13, 1937	118° 47′ E	10° 43′.8 N	30.4 fathoms

Bottom samples were also taken at irregular intervals by hand lead apparatus.

Shallow-water deposits between the high-water mark and two feet below the low-water mark have been taken as of two categories: (1) Marine fauna—collaborating with Mr. J. Domantay of the Department of Zoölogy, University of the Philippines; and (2) marine flora—collaborating with Mr. J. V. Santos of the Department of Botany, University of the Philippines.

SIAM

OCEANOGRAPHIC WORK is one of the functions of the hydrographic service of the royal Siamese navy. The activities of the Oceanography Section are performed by a Physical Oceanography Section, a Chemical Oceanography Section, and a Marine Biology Section.

The first of these three sections investigates tides, currents, and the topography of the sea bottom; the second makes analysis of sea water and marine deposits; and the third investigates life in sea water and studies the condition of the atmosphere over Siamese waters.

A BRIEF SUMMARY OF THE OCEANOGRAPHIC ACTIVITIES OF THE UNITED STATES NAVY IN THE PACIFIC OCEAN SINCE 1933

During the six years that have elapsed since the Fifth Pacific Science Congress, the United States Navy has continued to contribute to the science of oceanography in the Pacific, collecting data both through naval vessels and through the agency of its thousands of coöperating observers in the world's merchant marines.

The investigations of the Hydrographic Office may be divided into three fields, namely, the configuration of the ocean floor, dynamic oceanographical surveys, and ocean-current and surface-water temperatures.

In the first field, the sonic depth finder has played an important part in obtaining valuable information extending from the Arctic to the Antarctic and from the American continents to the far shores of Asia and Australia.

Interesting submarine features have come to light, new hypotheses have been formulated, and a vast panorama has been revealed in which the Hydrographic Office has played an important part. Based on the information received, the Hydrographic Office has recently issued a bathymetric chart of the South Pacific which delineates many submarine features heretofore unknown.

The U. S. S. *Ramapo* has been our greatest contributor in the matter of adding to the existing knowledge of the bottom configuration of the North Pacific Ocean. To the 8600 sonic soundings obtained in ten crossings up to February, 1931, over 32,000 additional soundings have been obtained by that vessel in subsequent crossings between the United States and Asiatic waters. When it is realized that not more than a decade ago little was known of the deep-sea hydrography of this vast ocean area, one can better appreciate the valuable contribution of the *Ramapo's* work to mariners and to the scientists who need adequate data of undersea topography on which to base their investigations.

A bathymetric chart of the North Pacific Ocean which is now in preparation in the Hydrographic Office, and which is expected to be ready for distribution early this fall, will show, besides a wealth of detail, some interesting submarine features discovered by United States naval vessels which are worthy of special mention in this paper.

The Ramapo Bank in latitude 27° 15′ N, longitude 145° 11′ E, with a least depth of 41 fathoms, lies 150 miles east of the Ogasawara Islands in a general depth of between 2400 and 3000 fathoms. It rises rapidly from a bottom floor of 1000 fathoms in an average distance of four miles; its southwestern slope drops from 45 fathoms to 800 fathoms in less than one-half mile.

When the numerous volcanic islands comprising the Nanpo Shoto and Kazan Retto, which extend from the entrance to the Gulf of Tokyo in a general southerly direction for over 600 miles, are taken into consideration, the discovery of the Ramapo Bank is not at all surprising. Further investigations of this general area are likely to reveal the existence of other submarine volcanoes.

The Ramapo Depth, 5771 fathoms, in latitude 30° 43′ 00″ N, longitude 142° 28′ 00″ E, discovered by the U. S. S. *Ramapo* on April 30, 1933, is the second greatest depth in the oceans.

Milwaukee Bank, in latitude 32° 28′ 00″ N, longitude 171° 55′ E, discovered by the U. S. S. *Milwaukee* in May, 1929, was confirmed by the *Ramapo* in November, 1935, and found to have a least depth of 160 fathoms (80 fathoms less than originally reported).

In the field of dynamic oceanographic surveys, the United States Navy, since the last Congress, in coöperation with the Oceanographical Laboratories of the University of Washington and the Scripps Institution of Oceanography, has made investigations in the Eastern North Pacific. These surveys include areas in the Aleutian Islands and along the coast of Central America, together with a number of lines radiating from the Hawaiian Islands. The data obtained have proved of inestimable value to the oceanographer in his studies of the chemistry of the sea, and have formed the basis for a number of papers prepared by the coöperating institutions.

The third field, namely, the investigation of surface ocean currents, and sea-water temperatures, has long engaged the attention of the Hydrographic Office. Since the beginning of the twentieth century, a vast reservoir of material received from the coöperating observers of the Hydrographic Office has accumulated in its files. Recently, through government sponsored projects, it has become possible to commence the correlation of this information. Over 1,000,000 individual observations relating to currents and sea-water temperatures in the Pacific Ocean have been reduced to punched cards, sorted into one-degree areas, and are now being analyzed. It is the intention of the Hydrographic Office to compile monthly temperature charts of the Pacific showing the average sea-water temperature in each one-degree quadrangle, together with the maximum and minimum temperatures. Concurrently, monthly current charts will be made delineating the resultant currents within the one-degree quadrangle. The completion of this project will help in the solution of many of the oceanographical and meteorological problems of the Pacific.

OCEANOGRAPHIC ACTIVITIES OF THE UNITED STATES COAST AND GEODETIC SURVEY IN THE PACIFIC, 1933–1939

THE UNITED STATES COAST AND GEODETIC SURVEY is the government agency charged with the conduct of hydrographic surveys of the waters adjacent to our coasts, the collection of tidal and current data, and the dissemination of the results of these operations in the form of nautical charts, coast pilots, tide tables, and current tables.

Remarkable progress during the past few years in the development of new survey methods and instruments by the Coast and Geodetic Survey has made possible an increase of nearly 100 per cent in the yearly output of offshore surveys. A sounding in 20,000 feet of water, which by the old wire method required about one hour, with the vessel stopped, is now made with the fathometer in a little over eight seconds with the vessel at full speed.

The old method of locating the sounding vessel's position by dead reckoning has been supplanted by the accurate radio-acoustic ranging method by which a sound wave travels under water from the vessel to a hydrophone, its receipt at the hydrophone being automatically indicated by a radio signal to the vessel. The velocity of sound through sea water and the location of the hydrophone being known, the distance between the vessel and the hydrophone can be quickly computed. Distances from two properly placed hydrophones give an accurate location of the sounding vessel.

The sono-radio buoy, developed in 1936, contains the hydrophone, a radio transmitter, and an audio amplifier, providing a complete unit for receiving the underwater sound and returning the radio signal to the ship. Experiments completed in 1935 by the ships *Pioneer* and *Guide* on the Pacific Coast indicate that radio-acoustic ranging should give positions within 50 meters up to a distance of 50 miles from vessel to hydrophone, and within 400 meters for distances as great as 200 miles.

In 1938 the original basic surveys of the coastal waters of the Pacific Coast from the Mexican border to Cape Flattery were completed. These surveys, in general, extend to the 1000-fathom curve, though in some areas the 2000-fathom curve is included. Wire-drag surveys of inshore areas have disclosed the existence of numerous shoal areas of importance to navigation.

Extensive hydrographic surveys are in progress along the Alaska Peninsula. En route to and from this area the three vessels engaged on the surveys have run approximately twenty sounding lines across the Gulf of Alaska.

The intricate topography revealed by modern surveys along the edges of the coastal shelf has given an entirely new picture of the submarine conformation, and has stimulated geologists to devise new and ingenious means of obtaining bottom samples and new instruments for observing the geological structures underlying the sea.

In the conduct of offshore surveys numerous temperature and salinity observations have been taken, primarily for use in determining the velocity of sound in sea water, but also of value in many other oceanographic studies.

Along the Pacific Coast of the United States twelve primary tide stations are maintained in continuous operation by the Coast and Geodetic Survey, in addition to two in Alaska and one in Honolulu. Besides supplying the necessary data for hydrographic surveys, the results of these operations are of basic importance in tidal research and in determining the relative changes in elevation of land and sea.

OCEANOGRAPHIC ACTIVITIES OF THE BUREAU OF FISHERIES IN THE NORTH PACIFIC AND ALASKA

No oceanographic work of any significance was carried on by the Bureau of Fisheries in this region between 1933 and 1938. In July, 1938, there was begun a physicochemical and biological survey of the waters of Bristol Bay, and of those of Bering Sea between Bristol Bay and Nunivak Island on the north, the Pribilof Islands on the west, and the Fox Islands on the southwest. There is also contemplated a survey of the waters along the southern shores of the Fox Islands and the Alaska Peninsula as far east as the Shumagin Islands.

The data collected will consist of grab samples and soundings for the purpose of describing the character and contours of the bottom, water samples at 10-meter intervals for salinity and oxygen analysis, temperatures at 10-meter intervals, currents, both tidal and drift, and plankton samples as taken by vertical hauls. The type of equipment used and the method of sampling will be in accordance with those used by the Oceanographic Laboratories of the University of Washington.

This program of work is being carried on in coöperation with the United States Coast Guard and the Oceanographic Laboratories of the University of Washington. The Coast Guard is providing the ship, and its maintenance, used in the surveys, and the University of Washington is providing laboratory space for the analysis of the samples and compilation of the data.

During the summer of 1938, using the United States Coast Guard Cutter *Red Wing,* a large number of stations were occupied in Bristol Bay, the stations being spaced about ten miles apart. The positions of the stations were planned so that they not only extended approximately north and south across the bay, but also ran the length of the bay east and west. The oceanographic work planned for 1939 includes a detailed series of observations, physical, chemical, and biological, before, after, and during the major run of salmon.

SCIENTIFIC ACTIVITIES OF THE NATIONAL CANNERS ASSOCIATION (NORTHWEST BRANCH), SEATTLE, WASHINGTON

By Ernest D. Clark

The National Canners Association is a nation-wide organization of packers of food products which are sterilized by heat. The Association carries on scientific work connected with problems arising in the canning industry. The Northwest Branch, founded in 1918, specializes on problems connected with the salmon industry, though it also does some work on other products canned in the northwestern portion of the United States. An office and laboratory are maintained in the Skinner Building, and an inspection laboratory at Pier 40, Seattle.

Probable source of certain abnormal odors in canned salmon.—Ingestion of certain odoriferous planktonic pteropods is held responsible for a garliclike odor in the canned salmon. This phenomenon, usually very rare, was rather common in a relatively small district in the 1936 salmon canning season.

Physical and chemical changes in the pink salmon during the spawning migration.—A study of this subject was undertaken coöperatively, being based on biological work by the United States Bureau of Fisheries and chemical investigations performed by the Northwest Branch of the National Canners Association. Characteristic changes in appearance and chemical composition due to starvation and sexual adjustments are brought out.

Salmon inspection.—In 1934 the description of the inspection methods for the examination of canned salmon was published, which summarized a long series of studies begun in 1920. During the six-year period (1933–1939), a total of over 18,000 parcels (containing some 33,000,000 cases) have been inspected and separately reported to the packers. A wealth of information on various factors of workmanship, quality, and condition found in some 1,000,000 sample cans has been recorded.

Crystals in canned sea foods.—Under certain unknown conditions, magnesium ammonium phosphate, a compound which is probably always present in canned salmon, forms small crystals of struvite which have from time to time given rise to apprehension on the part of the consumer through the mistaken impression that the material was glass. A study of the conditions leading to the formation of these crystals has been initiated in the hope that methods may eventually be discovered by the use of which their formation may be prevented.

Indol as an indication of decomposition.—Several experimental packs exhibiting successive stages of decomposition have been prepared. A study of the indol contents of these packs was made in order to test the reliability of an unpublished chloroform-extraction method for indol and the significance of indol as an index of decomposition.

The quantitative estimation of incipient decomposition in canned salmon.—The Association of Pacific Fisheries and the Northwest Branch of the National Canners Association sponsored and financed an investigation at Stanford University, the purpose of which was to appraise certain chemical degradation products for reliability as indicators of decomposition. Indol, hydrogen sulfide, and volatile nitrogen compounds were discounted; volatile acids appeared to be the most promising.

The bacteriology of salmon canning.—Thousands of cultures were obtained from hundreds of representative salmon and their environment, both while alive and in process of transportation and conversion into the canned product. Valuable conclusions were reached, from which many helpful suggestions were obtained. This investigation was likewise financed by the Association of Pacific Fisheries and the Northwest Branch of the National Canners Association.

Vitamins in canned red salmon and changes during storage.—A three-year coöperative study has been arranged with the University of Washington to study the vitamins in canned red salmon. An experimental pack, the history of which is definitely known, has been prepared and will serve as a basis for the study, which will be made by the holder of the Fairchild Scholarship in Pharmacy.

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OCEANOGRAPHIC ACTIVITIES OF THE UNITED STATES COAST GUARD SINCE 1934

Considerable attention has been given to oceanographic investigations in the Bering Sea and the Arctic Ocean, largely through the efforts and interest of Commander F. A. Zeusler of the United States Coast Guard. Working in collaboration with the Oceanographic Laboratories of the University of Washington, the United States Coast Guard has obtained much oceanographic information for the waters of these regions. The U. S. C. G. Cutter *Chelan* and the U. S. C. G. Cutter *Northland* have participated in the collection of oceanographic data since 1934. The United States Coast Guard, through the efforts of Commander L. V. Kielhorn, has observed a bank extending in a generally northwestern direction from Attu Island. The present charts show deep water, approximately 1800 fathoms, between Attu Island and the Komandorski Islands. The observations of Commander L. V. Kielhorn, however, indicate that there is a ledge extending across the entrance to the Bering Sea from Attu Island to the Komandorski Islands. This ledge is apparently from 200 to 600 fathoms in depth.

The official oceanographic activities of the United States Coast Guard are for the most part restricted to the waters of the Atlantic. The amount of work that has been done, particularly in the Bering and the Arctic, as intimated previously, has resulted from the marked interest evinced by Commander Zeusler.

In 1938 and 1939 the United States Bureau of Fisheries began an exhaustive oceanographic survey of Bristol Bay. This survey was made possible through the official efforts of the United States Coast Guard, which assigned the U. S. C. G. Cutter *Atlanta* for the Bristol Bay investigations.

OCEANOGRAPHIC ACTIVITIES OF THE BERNICE P. BISHOP MUSEUM, HONOLULU, HAWAII

By C. H. Edmondson

Members of the staff and associates of this institution who are interested in oceanography have limited their efforts, for the most part, to fisheries and marine biology. No attention has been given to physical and chemical oceanography. In the past several years several papers of fundamental importance on Pelecypoda of Hawaii, by Paul Bartsch, have appeared. Intensive work on *Teredo* in the local waters has been occupying the attention of Dr. C. H. Edmondson. Another paper of fundamental importance and of considerable economic interest, dealing with fouling organisms in the Hawaiian waters, by C. H. Edmondson and W. H. Ingram, has appeared. Some observations on the specific gravity of sea water adjacent to the Hawaiian Islands have recently been made by Dr. C. K. Wentworth, associate in geology.

Investigations of Hoffmeister and Ladd.—In 1934 Dr. Harry Ladd and Professor J. Edward Hoffmeister went to the Lau Islands (Eastern Fiji) under the auspices of the University of Rochester and the Bernice P. Bishop Museum in order to study the geology of the group. Twenty-six islands were studied and nine geologic sketch maps were made of the most important of these. Large collections of rocks, fossils, and water samples were made and have subsequently been studied by specialists, whose reports are nearly ready for publication. These include the following:

Igneous rocks	H. L. Alling, University of Rochester
Limestones	G. W. Crickmay, University of Georgia
Larger Foraminifera	Storrs Cole, Ohio State University
Smaller Foraminifera	Robert Kleinpell, U. S. Geological Survey
Corals	J. E. Hoffmeister, University of Rochester
Echinoids	Herbert Clark, Museum of Comparative Zoölogy
Mollusca	H. S. Ladd, U. S. Government Geologist
Crustacea	M. Rathbun, U. S. National Museum
Calcareous Algae	W. A. Setchell, University of California
Water samples	E. G. Moberg, Scripps Institution

Rock sequence.—The oldest rocks of the islands are mounds of tuffs, agglomerates, and some flows of andesitic lava. These rocks are widely scattered throughout Lau, and have been designated by us the Lau volcanics. Deposited on them are several hundred feet of bedded limestone which belongs to the upper part of the "Lower Miocene" of the East Indian section (State "f" of the Van der Vlerk-Umbgrove classification). These limestones are also widespread and are given the name Futuna limestone from the type section near the village of Futuna, Vanua Mbalavu. A second period of volcanism gave rise to flows, tuffs, and agglomerates of a more basic character than those of the Lau formation, and these have been named the Koro Mbasanga volcanics. A few areas show a younger limestone, known as the Ndalithoni limestone, overlying the Koro Mbasanga volcanics. The fauna of the younger limestones reveals an Upper Miocene or Pliocene age.

Basin-shaped islands.—Several of the limestone islands of Lau are basin-shaped and have been described as elevated coral atolls by various writers. Our studies indicated that most of these do not have the composition of coral reefs and that they are products of subaerial solution. With respect to a few, such as the island of Tuvutha, we may be dealing with the foundations of atolls. In other words, it may be that the coral reefs have been eroded away and the bedded limestones which now are found there represent the platform on which the reefs grew. If this is so, the original basin shape of the atoll has been preserved as solution continued.

Ladd and Hoffmeister have been interested in building up a stratigraphic sequence in the South Seas. They have been trying to date geologic events which gave rise to the present conditions of the islands. This has been done by them in Western Fiji, Lau (Eastern Fiji), and Tonga. To the west of these groups lie islands which possess older rocks; to the east are younger islands. The next field for detailed stratigraphic study is either the New Hebrides and the Solomon Islands to the west, or the island groups to the east (Society, Tuamoto, Cook, etc.). Only after this has been done can a clear-cut picture of the sequence of gelogic events be arrived at in this part of the world.

In 1937, a complete list covering the publications and activities of the Bernice P. Bishop Museum was published.

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OCEANOGRAPHIC ACTIVITIES OF THE HOPKINS MARINE STATION, PACIFIC GROVE, CALIFORNIA

By Austin Phelps

The hydrographic investigation of the water of Monterey Bay carried out by the Hydrobiological Survey, a joint project of the California State Department of Natural Resources, Division of Fish and Game, and the Hopkins Marine Station, Stanford University, has been continued with but one serious interruption until the spring of 1938. As has been done since 1929 when the survey was begun, weekly water samples were taken in Monterey Bay at various levels down to 900 meters, from the Fish and Game patrol launch *Albacore*. In addition to the routine observations of temperature, chlorinity, silicate, and phosphate, determinations of the oxygen and nitrite content of the water were made during 1936 and 1937.

In 1936 and 1937, thanks to the courtesy of the Division of Fish and Game in making occasionally available to us the larger patrol vessel *Bluefin,* it became possible to extend our work to include a series of eight stations in the open ocean, along the 36° 40′ parallel, between Monterey Bay and the 128th meridian. These stations were visited at irregular intervals, and the water was investigated to a depth of 2000 meters.

On the basis of temperature observations made in Monterey Bay from 1929 to 1934, Skogsberg has divided the annual changes which take place in the upper 200 meters of water in this region into three seasons, each represented by water of a different origin. An analysis of the chemical data shows that the annual fluctuation of the concentrations of chlorinity, silicate, phosphate, and oxygen in the upper layers of water, is thoroughly consistent with Skogsberg's theory in regard to the origin of the water during each of the hydrographic seasons.

The chemical investigation of the deep water has revealed a number of rather unexpected features with respect to vertical distribution. Both in Monterey Bay and in the open ocean the phosphate increases in concentration with depth down to the 600- or 700-meter level, and then decreases with depth through a zone about 100 meters thick, below which it again increases with depth, coming to a maximum at the offshore stations at depths of between 1000 and 1200 meters. The zone of reversed gradient is occasionally not observable, and its depth, together with the depth of the maximum concentration of phosphate, differs slightly at different times, but these variations bear no relation to the seasonal changes occurring in the upper layers of water. A striking anomaly in the deep water of Monterey Bay is the occasional sudden disappearance of much of the phosphate below the 500-meter level. This phenomenon may last from one week to three months, and may extend over a zone having a thickness of from 100 to 400 or more meters.

The oxygen concentration decreases with depth to arrive at a minimum between 600 and 800 meters, below which it gradually increases with depth. The thickness of this oxygen minimum zone may vary from 100 meters to 400 meters, and the minimum oxygen concentration is lowest when the oxygen minimum layer is thickest. The oxygen content in the open ocean shows a continuous increase with depth below 800 meters, and this rise is quite unaffected by the maximum phosphate content, which is found between 1000 meters and 1200 meters.

ACTIVITIES OF THE SCRIPPS INSTITUTION OF OCEANOGRAPHY, LA JOLLA, CALIFORNIA

By H. U. SVERDRUP

ON NOVEMBER 13, 1936, the Institution's boat, *Scripps,* which in 1934–35 had been completely overhauled and reëquipped, was lost by explosion and fire. On April 5, 1937, Mr. R. P. Scripps bought the 104-foot schooner *Serena,* which, after remodeling, he gave to the Institution. On its transfer, its name was changed to *E. W. Scripps*. In addition to the crew, the *E. W. Scripps* can accommodate a scientific party of six, contains adequate laboratory space both on deck and below deck, and carries two winches for oceanographic work, one provided with 2000 feet of $\frac{5}{32}$-inch wire rope and one provided with 2000 feet of $\frac{3}{8}$-inch wire rope. The normal cruising radius under power is 2000 miles, but this can be extended by taking fuel on deck and by using the sails.

Expeditions and oceanographic data.—From June, 1935, until November, 1936, the *Scripps* occupied a number of oceanographic stations in the waters near the coast of southern California between San Diego and Santa Barbara. In 1937, when the Institution had no vessel at its disposal, three cruises were made in coöperation with the California State Fisheries Laboratory, using their vessel, the *Bluefin*. Nearly thirty stations were occupied on each cruise along four lines running at right angles to the coast. The lines were 70 miles apart and 160–180 miles long, the northern beginning off Port San Luis and the southern off San Diego. In 1938 all these stations were occupied by the *E. W. Scripps* on six cruises in alternate months from February to December, except when, in April and October, bad weather prevented the completion of the work. On the *Bluefin* cruise, observations were made at standard intervals down to as low as 2000 meters, but on the *E. W. Scripps* cruises the work was confined to a depth of 600 meters. On the latter cruises quantitative catches of phytoplankton were made at seven depths at all stations, and vertical hauls of zoöplankton were conducted on all cruises except the first one.

In 1933, 1934, and 1935 the U. S. S. *Hannibal* occupied a large number of oceanographic stations in the Gulf of Panama and off the coast of Panama and Costa Rica. In 1933 R. H. Fleming of the Institution's staff spent about three months aboard the *Hannibal* as special observer. In 1934 the U. S. S. *Bushnell* occupied 18 stations between Adak in the Aleutian Islands and Pearl Harbor in the Hawaiian Islands. Roger Revelle of the Institution's staff accompanied the *Bushnell*. In November, 1936, 10 stations were occupied by the U. S. S. *Louisville* between San Pedro and Pearl Harbor. This work was under the charge of E. G. Moberg of the Institution's staff.

In addition, the Institution has received subsurface data from various stations close to the American coast occupied by vessels of the United States Coast and Geodetic Survey. About forty subsurface data were obtained by the *Valero III* in 1934–35 from the area off the coast of Peru in about latitude 10° S. A large number of surface data have been submitted to the Scripps Institution.

Physical oceanography.—The above-mentioned data have all been discussed and published or prepared for publication except those of 1938, which are under preparation. The *Bluefin* observations in 1937 and the observations of the *E. W. Scripps* in 1938 have shown that off the coast of southern California a big eddy appears to be present during the greater part of the year. This eddy is especially well developed during the period of upwelling when the offshore branch of the eddy carries cold upwelled water toward the south, whereas the inshore branch carries water of higher temperature toward the coast, but this inshore branch reaches only to the Channel Islands.

In order to explain the observed distribution of temperature and salinity it appeared necessary to assume that an intensive quasi-horizontal mixing takes place, at least down to a depth of 500 meters. This process of mixing can be dealt with as a process of diffusion, by introducing a coefficient of diffusion of the order of magnitude 10^6 cm^2/sec. It is probable that this mixing is maintained by eddies of dimensions up to 10 or 20 km. and that the velocities may be up to 20 or 30 cm/sec. Measurements of current by F. P. Shepard and Roger Revelle by means of a meter suspended on a tripod only 21 cm. from the bottom show that irregular currents having velocities up to 20 cm/sec. are found near the bottom at depth between 50 and 800 m. The presence of such irregular currents at these depths may be considered a confirmation of the conclusions with respect to eddy motion based on distribution of temperature and salinity.

E. C. LaFond has conducted a study of the relation between coastal surface temperatures and sea level and has shown that low surface temperature corresponds to low sea level and vice versa. By means of oceanic data off the coast it has been established that variations in sea level are closely associated with changes in the distribution of density of the coastal waters. Hence, the records of sea level can be used in the study of coastal currents.

In 1936 a series of measurements of penetration of light was made by means of a photocell, and in the summer of 1937 a Pettersson transparency meter was constructed and tried out. This instrument was used in August, 1938, for measuring at about 20 stations the transparency of water at different depths between the surface and 60 meters. This work was conducted by R. T. Young, Jr., of Worcester Polytechnic Institute.

G. F. McEwen and his associates have continued their study of forecasting seasonal air temperatures and precipitation on the basis of cycles and correlation with ocean temperatures. The public interest in these forecasts has warranted their annual publication.

Mathematical methods needed in problems of vertical flow or upwelling combined with turbulence have been further developed. Extensive quantitative applications to data on temperature and salinity in the San Diego area have been made. For convenience, each stage in the computation process was carried through for all the data, after the complete method had been tested on a few examples, and tables were prepared to facilitate the computations.

Further developments were made in methods derived earlier of calculating the velocity of horizontal currents from surface temperatures. Extensive applications of the method have been made to North Pacific Ocean data and a paper presenting these results is in preparation.

As a basis for making such calculations, a study of interrelations between processes of radiation, convection, and evaporation near the sea surface was made, which also provided theoretical values of the mean annual rate of evaporation at different latitudes.

An extensive W. P. A. project employing about twenty-five computers for compiling ocean observations reported by navigators in the Pacific, sponsored by the Scripps Institution about three years ago, is still in progress under the supervision of an officer of the United States Hydrographical Department. Thus ocean observations made since 1924 have been compiled on convenient standard forms, from which information is transferred to punched cards for use in Washington, D. C. By special arrangement with the Hydrographic Department, the compilations on these standard forms are kept on file at the Scripps Institution. These data are being averaged with respect to one-degree quadrangles and months for each year, thus providing a basis for determining changes from year to year in the Japan Current off our coast, as well as the Humboldt Current off the coast of South America.

Researches on smaller bodies of water, lakes or storage reservoirs, where relevent conditions are more completely observed, and processes are less complex than in the sea, are helpful in attacking problems of the sea. A paper presenting an extensive series of such observations and their interpretation in San Diego County was prepared by McEwen.

Daily observations of surface temperature and salinity have been continued at the following six stations:

Scripps Institution Pier	Latitude 32° 52′ N
Hueneme	Latitude 34° 9′ N
Pacific Grove	Latitude 36° 38′ N
North Farallon Island	Latitude 37° 42′ N
Blunt's Reef	Latitude 40° 27′ N
Balboa	Latitude 33° 36′ N

A study of the energy relations between the sea surface and the atmosphere has been completed, and by means of local observations of the vertical temperature gradient in the sea, together with the distribution of solar radiation and the amount of radiation penetrating the sea surface, the resulting evaporation from the sea has been computed. Methods for use in summarizing numerical field data have been critically examined.

Estimation of ocean currents from surface temperature distribution has been made. McEwen has devised formulas, based on considerations of surface energy relations, for estimating surface ocean currents from the distribution of temperatures. One such formula consists of a quotient of two quantities which in practice are subject to rather serious random errors which (ideally) are normally distributed in both numerator and denominator. Under the hypothesis of normal distribution, the probability distribution of values of the quotient has no standard deviation and its arithmetic mean is indeterminate, so that it has no "law of large numbers." A statistical estimate of the "true value" of such a quotient has been obtained which possesses a definite mean and satisfies a "law of large numbers" (how strongly is as yet not determined), although this estimate also has no standard deviation. These characteristics of an estimate are of importance for "least squares" treatment of data, and, for example, for estimating total transports of water over a period of time; it is hoped that this estimate will be found satisfactory.

Several applications of statistical methods to biological problems have been developed by McEwen and Gordon. Mr. Gordon has developed a new method for computing "most probable" bacterial populations from the results of successive tenfold dilutions of the sample. It is believed that tables based on the new formula will give better agreement with experimental results than Halvorson and Ziegler's tables, which are now in use.

Dr. C. E. ZoBell compared plate counts and successive dilution estimates taken from tables by Halvorson and Ziegler on the same material, with unsatisfactory results. The unsatisfactoriness is attributable to varying skewness of certain probability distributions, of which Halvorson and Ziegler's tables give the modes. Formulas have been devised for obtaining geometric means of these distributions, together with logarithmic standard deviations. It is expected that much better agreement with plate counts will thus be attained. Computation of tables to replace those of Halvorson and Ziegler will be necessary before this can be actually tested, also for practical use. It is hoped that funds will become available to enable this to be done. Further material is yet to be published.

Chemistry.—The work in the chemical laboratories under the charge of E. G. Moberg has for the most part dealt with routine determinations of salinity, oxygen, phosphates, and various components of the buffer mechanism. Determinations have been made on samples regularly collected at the Institution's pier as well as on samples obtained on the above-mentioned cruises.

Further investigations of the buffer system of the sea have been conducted by D. M. Greenberg of the University of California, Berkeley; Esther Allen, and Messrs. R. H. Fleming and R. Revelle, and later by Mr. John Lyman. A study of importance in comparing the results of determinations of titratable base or alkalinity obtained by different methods was carried out in coöperation with P. H. Mitchell of Brown University.

Some attention has been given to the atmospheric nitrogen content of sea water and experiments have been made to determine nitrogen by means of the Van Slyke blood-gas apparatus. It is believed that a method has been devised that will prove practicable in laboratories on shore and possibly also on board ship.

A method for detecting small differences in the carbon dioxide content of the air that may be correlated along the coast with the direction of the wind has been developed, and a rapid and scientific method for determining arsenic was applied to sea water by T. H. Winnick of the University of California, Berkeley.

With the assistance of the Works Progress Administration workers, numerous determinations of the fixed nitrogen content of bottom samples from various parts of the Pacific were made and a number of water samples were analyzed for organic and ammonia nitrogen and for calcium. Various methods for determining iodine in sea water were tried by W. L. Burdick and J. Cunningham. By means of one of these methods, accurate information regarding the iodine content of a number of samples was obtained not only from the surface but also from depths down to about 1000 meters. A study of methods for the determination of manganese and iron in sea water has also been begun. Robley D. Evans made a study of the radioactive substances in sea water, in marine plants and animals, and in the bottom deposits off the coast of southern California.

Submarine geology and marine sediments.—In 1935 F. P. Shepard of the University of Illinois undertook dredging for rocks from the walls of the submarine canyons near La Jolla, and in 1938 this work was continued and greatly extended through a grant from the Geological Society of America by means of which Mr. Shepard had the use of the *E. W. Scripps* in alternate months. Large quantities of rocks were brought up from a number of localities, cores of bottom sediments up to 12 feet in length were obtained, and detailed soundings were made in many areas. Roger Revelle of the Institution's staff took part in this work and conducted simultaneously laboratory studies of bottom sediments. A large amount of mechanical analyses of sediment samples collected by the *Scripps* off the southern California coast were completed. The results show distinct relation between the grain size of the sediments and the topography of the bottom. Similarly, the amount of organic nitrogen in the samples which were determined in the chemical laboratory showed distinct relation to the configuration of the bottom. Revelle completed his discussion of the bottom samples collected by the *Carnegie* in the course of her work in the Pacific. Together with R. H. Fleming measurements were made of the variation with depth of the currents close to the bottom. It was found that in shallow water the profile of the current near the bottom corresponded closely to the velocity profile which has been established in laboratories as characteristic for flow over a rough surface. Miss Stina Gripenberg of Helsingfors, Finland, was engaged in 1937–38 in studies of the carbon content of sediments.

Marine microbiology.—C. E. ZoBell, in charge of the bacteriological studies, has continued his work on bacteria in sea water and in bottom deposits. Five new species have been isolated which produce ammonia from low concentrations of urea in sea water. Observations on the influence of temperature, organic matter, pH, redox potentials, and salinity on the activities of nitrifying and denitrifying bacteria indicate that in the sea the redox potential is perhaps the most important factor. Multiplication, proteolysis, carbohydrate fermentation, ammonification, and nitrification in marine bacteria have been observed at 0° to —2° C., which indicates that bacteria are functional at the low temperatures encountered in the deep sea.

With the assistance of D. Q. Anderson the vertical distribution and relative abundance of bacteria in marine sediments which activate a number of different physiological processes of oceanographic significance have been estimated. It has been shown that bacteria have a great capacity to affect in marine bottom deposits the O/R potentials which are of bacteriological, geological, and chemical significance.

Assisted by Mr. Sydney Rittenberg, a microasbestos calomel half-cell has been prepared for measuring the O/R potentials of anaerobes in oval tubes. The device makes it possible to study the influence of bacteria upon the O/R potential and also to study the influence of O/R potentials upon the activity of the bacteria.

Chitin-digesting bacteria have been found to be quite widely distributed in sea water and bottom deposits. They were found in abundance in the digestive organs of squid, thereby indicating that they may aid marine animals in the digestion of the resistant chitin which constitute the exoskeletons of most crustacea. Lipoclastic bacteria which liberate higher fatty acids from lipins and utilize the glycerol have been demonstrated in marine materials. These, together with those which create extremely reducing conditions, may account for the formation of long-chain hydrocarbons found in petroleum.

Mrs. C. B. Feltham has continued the experiments on the bacterial nutrition of marine organisms. Mussels have thrived for 14 months in the dark on a diet consisting exclusively of bacteria.

The importance of the presence of solid surfaces to which bacteria can attach themselves has been examined. It is believed that the low number of bacteria per unit volume in the ocean is associated with lack of surfaces per attachment. For further studies of the abundance of bacteria an improved bacteriological water sampling bottle has been perfected.

Phytoplankton.—W. E. Allen has continued the daily collections of phytoplankton from piers at Scripps Institution and Point Hueneme more than 100 miles farther north. The microscopic work and preliminary calculations have been completed up to 1937 and cover now a period of 18 years. A large number of surface plankton catches have been obtained from various vessels, the collections have all been examined and the results published. The surface and subsurface collections of phytoplankton which were made on the 1938 cruise of the *E. W. Scripps* have been studied and show especially that the abundance of diatoms may be as great at a distance of 180 miles from the coast as close to the coast.

Miss Easter E. Cupp has analyzed a number of phytoplankton catches by means of the centrifuge method and has spent the greater part of her time in preparing a taxonomic paper on plankton diatoms of the southern California region.

Foraminifera.—T. W. Vaughan published a number of papers on fossil foraminifera. E. H. Myers has succeeded in working out the life history of a local species of foraminifera known as *Patellina corrugata,* and has extended his studies to another form in which the cycle in all respects conforms to that of *Patellina.* M. L. Natland has continued his studies of the ecological relations of the foraminifera in the Gulf of Catalina.

Zoöplankton.—Martin W. Johnson has been engaged partly in the study of the life history of certain copepods and partly in studies of the geographic distribution of copepods and other forms of zoöplankton. Among others, the development stages of the oceanic copepods *Eucalanus elongatus* has been completely worked out and a report has been published on the distribution in the Pacific of the varieties of this form. The large accumulation of collections which were made by the *E. W. Scripps* in 1938 is being examined with the assistance of C. C. Davis. C. R. Monk has continued a systematic and distributional survey of the harpacticid copepods of the Pacific coast.

Physiology of marine organisms.—D. L. Fox, in collaboration with G. W. Marks and others, has concluded a study on the habitat and food of the California sea mussel. Further work on the mussel has been made possible by assistance from the Works Progress Administration. Experiments dealing with the biochemical effects of hypotonic and hypertonic solutions of sea water upon tissues have been conducted. It has been established that the mussel propels water through the gill chamber at an average rate of 2.5 l/hr. One of the chief lines of research has been the study of various carotenoid pigments in marine materials and marine animals, with special reference to nutrition. Part of this study, that dealing with carotenoid pigments in marine fishes, has been undertaken in coöperation with F. B. Sumner. The characteristic absorption curves of different pigments have been established spectroscopically.

Biology of Fishes.—F. B. Sumner has continued his studies of the protective value of color changes in fishes, and has experimentally established that fish-eating birds catch a much greater proportion of those fishes which do not harmonize with the background. The work of F. B. Sumner and his collaborators has, however, mainly dealt with the quantitative determination of the amount of pigments formed in fishes which have been subjected to different conditions with respect both to color of background and to incident light. It was found that the amount of melanin extracted from a given lot of fishes bears an inverse relation to the albedo of the background, probably varying inversely as the logarithm of the albedo. Intensity of incident light also played a part in determining the production or loss of melanin, but under the degrees of illumination employed so far, the influence of this factor was small in comparison with that of the albedo of the background. A series of experiments have been commenced with a view to discovering some of the physiological differences between fishes which have been acclimatized to widely different temperatures.

P. S. Barnhart has completed a monograph, *Marine Fishes of Southern California,* illustrated by 292 figures.

Studies on "fouling growth."—In 1937 coöperation was established between the United States Navy Bureau of Construction and Repair and the Scripps Institution in order to study the organisms which cause fouling growth on ships' bottoms. These studies form a continuation of work which was conducted at the Institution over a long period of years but which had to be discontinued because of other pressing demands. Mr. W. F. Whedon, who has been engaged by the Bureau of Construction and Repair to carry on these studies, has been engaged mainly in examinations of the primary film formed on submerged surfaces.

Publications.—In the years 1933–1938, 265 papers have been published. A partial list follows, which includes only those papers which deal with general aspects of oceanographic problems or with conditions in the Pacific Ocean.

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MARINE RESEARCH AT THE UNIVERSITY OF SOUTHERN CALIFORNIA

By Rufus B. von KleinSmid

Owing to the generosity and the scientific interests of Captain G. Allan Hancock, the study of marine biology in the Pacific Ocean has already taken a decided step forward. Beginning with the launching of the *Velero III* in 1931, Captain Hancock has given scientists and scientific work first consideration during the past eight years.

In December, 1938, the initial steps were taken to found the Allan Hancock Foundation for Scientific Research at the University of Southern California, the *Velero III* becoming the floating marine scientific laboratory for the Allan Hancock Foundation.

The *Velero III* is an all-steel Diesel cruiser, 195 feet in length, with a cruising radius of 12,000 miles and capable of operating independently of supplies for a three-months period. There are commodious quarters for 14 scientists in addition to a crew of 18. Necessary changes are being made constantly to increase the effectiveness of the *Velero III* for marine research.

A brief analysis of the work on the *Velero III* under the command of Captain Hancock since 1931 shows a record of eight major cruises in that number of years, with a total of more than 600 days in the field.

Five of the eight cruises have been in waters adjacent to Mexico, Panama, Malpelo Island, Colombia, the Galápagos Islands, Ecuador, and Peru. Each trip has so varied in time and weather conditions that each succeeding trip has emphasized the fact that scientific possibilities for the *Velero III* in the future are almost unlimited in this area, or any other area.

The scientists who have worked on the *Velero III* on these voyages have been pushing inland from the coast, southward toward Juan Fernandez Islands, and westward and northward to the Farallones, as rapidly as time has permitted them to make the most of the opportunities offered.

The fact that the work on the *Velero III* demands the best of specialists in the several fields investigated accounts for the list of other institutions which have collaborated in the project so far: the Smithsonian Institution, Dr. Waldo Schmitt; the University of Michigan, William Randolph Taylor; the University of British Columbia, Dr. C. McLean Fraser; the University of Nebraska, Dr. H. W. Manter; Harvard University, Dr. Hubert Lyman Clark; the California Academy of Sciences, Dr. Leo Hertlein; Stanford University, Dr. George Myers; and the University of California at Los Angeles, Dr. Loye Miller.

The San Diego Zoölogical Society and the Los Angeles Museum have been aided in various ways by the long and short trips of the *Velero III*, respectively.

The 1939 cruise of the *Velero III* extended into the Atlantic as far as Trinidad off the coast of Venezuela, establishing 59 stations and accumulating the usual records. On this same trip additional stations were established in the Pacific, bringing the total up to 974 for the Pacific Ocean since 1931. Of this number in the Pacific Ocean, 271 stations are in the Gulf of California.

Most of the collections made on these trips of the *Velero III* are now at the University of Southern California in the Old College Building. When the new building is completed approximately a year from now, the collections are to be placed in the middle unit, which will consist of a vault extending through six floors. Surrounding this vault on three sides, on six levels, are the unit research rooms, with easy access into the vault on each level. A number of the partitions are to be left out in order to provide a series of larger rooms for the work on certain collections.

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ACTIVITIES OF THE OCEANOGRAPHIC LABORATORIES OF THE UNIVERSITY OF WASHINGTON, SEATTLE, WASHINGTON

By Thomas G. Thompson

Since the Fifth Pacific Congress, many of the findings of the Oceanographic Laboratories have been reported in various scientific journals. An extensive program representing both the biological and physical sciences, as applied to the various phases in oceanography, continues in operation.

Field laboratories at Friday Harbor, San Juan Archipelago.—Through the efforts of Dr. Lyman Phifer in coöperation with other members of the staff, several series of continuous observations have been made throughout the six-year period. Automatic recording has yielded much valuable information on solar radiation, tidal fluctuations, barometric pressure, and the temperature of the air a few meters above the sea surface. Daily sea temperatures and salinities have been determined throughout this period from the observation pier, and every fifth day analyses were made for the various nutrient constituents of the sea water, the dissolved oxygen, hydrogen ion concentration, and buffer capacity. Frequent observations regarding the extent of the plankton were made, with special emphasis on the phytoplankton. Data on rainfall have proved of considerable interest and recently more detailed investigations on precipitation have been initiated.

Expeditions.—The motor ship *Catalyst,* 75-foot research vessel of the Laboratories, well equipped with laboratory space and scientific apparatus, has occupied a very large number of stations in the Puget Sound region, the San Juan Archipelago, and the Northeast Pacific beyond the continental shelf. The cruising range of 3500 miles has enabled the vessel to take cruises as far north as Skagway, Alaska, and to San Francisco. About a half-dozen cruises have been made to the Queen Charlotte Islands to study the sea life of the region and to observe the physical and chemical conditions of the waters. Professor C. McLean Fraser of the University of British Columbia, the distinguished specialist on hydroids, was aboard on one of the cruises and was able to add considerably to the knowledge of the hydroids of the Pacific Coast.

At most of the stations occupied by the *Catalyst,* vertical net hauls were made. In addition to the temperature and salinity data of the water at various depths, samples were analyzed for dissolved oxygen, phosphates, silicates, nitrites, hydrogen ion concentration, and buffer capacity. Water was also collected on various occasions for the study of a number of other constituents of sea water. A great number of dredges have been taken in the various regions where the water was less than 400 meters in depth. The results of the dredges over an eight-year period are now being assembled for a monograph by Professor John E. Guberlet.

United States Navy.—Several representatives of the Laboratories at various times accompanied the U. S. S. *Gannett, Argonne, Patoka, Swallow,* and *Oglala.* Sections from 50 to 100 miles in length, with stations every 10 miles, were run from different points in the Aleutian Islands southward into the Pacific and northward into the Bering Sea. Some of the sections were occupied twice in one season and the observations duplicated the following year.

Two long sections have been seen, one from Dutch Harbor, Alaska, to the entrance of the Strait of Juan de Fuca, and the other from the Hawaiian Islands to the Strait of Juan de Fuca, with stations 100 miles apart. Samples were taken to depths of 2500 meters.

The United States Coast Guard.—Because of the marked interest of Commander Frederick A. Zeusler, U. S. C. G., in oceanography, an opportunity was offered to the Laboratories to place two representatives aboard the U. S. C. G.

Cutter *Chelan* in 1934 and 1935. Several of the sections studied previously in coöperation with the U. S. Navy in 1934 were reoccupied, but most of the investigations were confined to the Bering Sea proper. In Bering Strait, direct current observations at various depths, with use of an Ekman current meter, were made at different times. The general physical and chemical properties of the waters of the regions were investigated, and a number of plankton tows were made. In the greater parts of the Bering Sea there was a northerly movement of the waters. Current magnitudes ranging up to 1.5 knots were measured, and these conformed locally to the shore lines and bottom contours. The waters of the northern Bering Sea moved rapidly at all depths, and in Bering Strait the hourly discharge of water into the Arctic was 0.5 cubic nautical mile per hour. Very low temperatures were found in some of the intermediate waters near Adak Island in the Aleutian chain. It was attempted to show that these cold waters originated off the Siberian Coast, the Gulf of Anadir probably being the source of this water. The salinity values for the Bering Sea were low in the northern portions, owing to the discharge of the great rivers like the Yukon and Kuskowim. In this region there was a stratification of the waters, the upper layer being comparatively warm water of a low salinity resting on a much colder water of a higher salinity. This is particularly noticeable in the central and western Bering Sea north of the Pribilof Islands. Homogeneous water was observed between St. Lawrence Island and the Diomedes, the result of marked mixing due to turbulence. Evidence of upwelling and mixing by turbulence was also found in the waters just north of the Aleutian ridge. The minimum oxygen zone, characteristic of the Pacific waters, occurred on both sides of the Aleutian ridge at depths ranging from 350 to 1000 meters.

When Commander Zeusler assumed command of the U. S. C. G. Cutter *Northland* in 1937, a series of observations was again made with representatives from the Laboratories, and was partly repeated in 1938, special emphasis being given to waters of the Bering Sea, Bering Strait, and the Arctic Ocean along the coast of Alaska as far north as Point Barrow.

United States Lighthouse Service.—In coöperation with the Laboratories, the masters of the several lightships off the Washington coast are making temperature observations near the mouth of the Columbia River, Umatilla Reef, and Swiftsure Bank off the Strait of Juan de Fuca. Samples are also taken for salinity determinations. At various strategic points along the Alaskan coast, similar observations are being made at lighthouses.

The data together with that collected off the coast of the state of Washington will augment the data being obtained by the Pacific Biological Station at Nanaimo, British Columbia. This institution has obtained similar material over a much longer period of time from the lighthouses in British Columbia.

United States Weather Bureau.—The Laboratories own and maintain an Epply recording pyrheliometer at Friday Harbor. A record of both the direct and the diffuse solar radiation has been maintained since 1932. This record forms a part of the Weather Bureau's observations on solar radiation, the data being published at regular intervals.

Submarine solar radiation.—The study of submarine solar radiation was greatly accelerated by a grant-in-aid to Professor C. L. Utterback from the National Research Council in January, 1937. This grant made possible the construction of a new photometer so designed that it is possible to determine, simultaneously, the existing characteristics of scattered and transmitted submarine radiation. Also, determinations can be made on any selected components of submarine solar light as well as the total light at any desired depth. The photometer was found to be very effective in the determination of the relative intensities of both scattered and transmitted light. However, as relative intensities are insufficient for a more complete analysis, the instrument, during the latter part of 1937, was altered so that it is now used to measure the actual intensity of illumination in illumination units. The alteration involved a modification of such a nature that the spectral sensitivity of the light-sensitive cells was equivalent to the spectral sensitivity of the eye. Accomplishment of this made the deviations of the two response curves less than deviations of individual eyes from the average eye curve. Since these alterations were completed, a series of measurements have been made in the water of the Pacific off Cape Flattery, in the Strait of Juan de Fuca, Haro Strait, San Juan Archipelago, Bellingham Bay, Georgia Strait, and in Puget Sound. This was completed in the summer of 1938. The measurements have been analyzed and will be published soon. In the summer of 1939 an analysis will be made of the foot-candle contribution of several components of sunlight to the total illumination of various depths in the same waters. The study of long- and short-period cyclic changes in total illumination and its components was carried through 1935, 1936, and 1937, and will continue. The bearing of these results on biological processes has been analyzed in coöperation with the biologists of the staff. This analysis will continue, with emphasis on the effects of variations in luminous flux.

In connection with the study of solar radiation, the Laboratories are developing a daylight recorder which, when in operation, will furnish a valuable complement in correlating oceanographic data with the characteristics of solar radiation.

Radioactivity.—The Laboratories are now equipped with facilities for the determination of very small quantities of radium. Research in radioactivity of ocean water, ocean-bottom material, and marine organisms has been in progress during the last four years. In coöperation with the Coast Guard and by use of the *Catalyst,* several hundred "grabber" samples have been collected from the bottom of the ocean. The region from the Columbia River to Point Barrow has been systematically sampled and more than 100 samples have been analyzed. These analyses are sufficient in number and of proper distribution to furnish knowledge of the distribution of radium in bottom material along the coast and in the inshore waters. The collection has been materially augmented by core samples taken in fairly shallow inshore waters. A core sampler, effective in shallow water, was developed at the Laboratories and has been used for collection during the past two years. The Laboratories will soon be in possession of one of Dr. Piggot's core samplers. When this is in operation, the radioactivity research program will be materially extended. Provision has been made for analyzing the cores for radioactive materials as well as for other analyses.

A survey of the radium content of ocean-bottom materials in regions surrounding Vancouver Island was recently completed and the results published. The work on the distribution of radium from the state of Washington to Point Barrow is nearly completed and will be in the literature by the autumn of 1939.

Meteorology.—Since 1935 the meteorological investigations of the Oceanographic Laboratories have been considerably extended, owing to the addition of Dr. Phil. E. Church to the staff. The program now includes a number of microclimatological and micrometeorological studies in the Puget Sound area. Eleven rainfall stations have been established on San Juan Island in the San Juan Archipelago. The summer wind patterns within the channels of this region, the nature of the structure of the afternoon breezes in the Strait of Juan de Fuca, and of local sea breezes have been studied. Other problems that are receiving considerable attention are the structure of winds in gaps, the zone of stagnation between gorge and gradient winds, and the details of frontal structure. Studies dealing with the amount of evaporation of the waters of the Puget Sound region as well as that of the San Juan Archipelago have initiated a number of observations on the temperature, humidity, and wind-velocity gradients within the lower few meters above the water. Eventually analyses of the data being collected by the lightships along the Washington coast, as well as those obtained by lighthouses strategically situated in Alaska, are expected to yield much useful information.

Physical chemical studies.—Considerable emphasis has been placed on the study of the physical properties of sea waters of various concentrations and different temperatures, the latter in the ranges from 0° to 25° C. Using very refined measurements, the densities, electrical conductivities, and refractive indices have been determined and studies of viscosities have been initiated.

Any fundamental study of sea water calls for an intimate knowledge of the nature and properties of salt solutions. Much time has been spent on the study of simple and complex solutions composed of some of the major salts found in sea water. Phase-rule investigations on the deposition of marine salts by the freezing of sea water were inaugurated, but because much fundamental data were lacking on simpler systems, it was necessary to confine these phase-rule studies to tertiary and quaternary systems.

Chemistry of sea water.—Accurate methods of analysis are prerequisite to a precise study of the chemical characteristics of ocean water. Critical investigations have been made, under the direction of Dr. Rex J. Robinson, of the analytical methods for the determination of ammonia by nesslerization, phosphate by the ceruleomolybdate method, silicate by the Dienert-Wandenbulcke method, and nitrate by the reduced strychnine method. Analytical procedures for the determination of aluminum, boron, iron, copper, manganese, potassium, bromine, and zinc have been studied. Various standards to be used in the standardization of sodium thiosulfate solutions for the determination of dissolved oxygen by the Winkler method have been compared. Considerable work has been directed toward methods for the determination of total organic matter and organic phosphorus in sea water, since as yet the present methods are not entirely satisfactory.

The distribution of isotopic water in the several oceans at various depths has been investigated and found to occur in concentrations greater than in river water. The manganese content of ocean water varied slightly with depth and averaged 0.2×10^{-4} milligram atoms per liter. The boron content on 377 samples collected in the northeast Pacific varied from 0.125 to 4185 milligram atoms, the boron–chlorinity ratio being 0.023. A few variations from this ratio were observed which were greater than possible deviations due to experimental error. The determination of the buffer capacity of sea water has been greatly improved by the use of the glass electrode.

Detailed observations on the distribution of phosphates in the waters of the Strait of Juan de Fuca, San Juan Archipelago, and Puget Sound, as well as the Pacific Ocean, have been published. The high phosphate content of the waters of these regions was attributed to upwelling and turbulence. These studies in distribution of various chemical constituents have also included aluminum, ammonia, potassium, boron, bromine, albuminoid nitrogen, Kjeldahl nitrogen, copper, iron, and manganese. Strontium has been demonstrated to be present in many sea products and in concentrations approximating 0.2 milligram atoms per liter of sea water. Efforts to detect beryllium in sea water have given negative results.

Seasonal investigations of temperature, chlorinity, dissolved oxygen, phosphate, silicate, nitrite, hydrogen ion concentration, and the buffer capacity for the waters of selected stations in Puget Sound and the Strait of Juan de Fuca were begun in 1933 and have been continued to date. Studies of the variation of the composition of the waters of several regions as a result of tidal action have been made from time to time, and a summary of the observations has been published.

Attention has been given to the zone of minimum oxygen which occurs at approximately 800 to 1000 meters in the Northeast Pacific. The concentration of dissolved oxygen decreases with increase in depth until this minimum zone is reached, where a concentration of 0.02 milligram atom of oxygen per liter of water is noted. Below this zone the dissolved oxygen gradually increases again. Similar zones were obtained in several sounds along the coast of British Columbia, which were connected to the ocean by a narrow shallow channel. Minimum zones were likewise observed in the deeper portions of the western Bering Sea.

Biochemical investigations.—The biochemical investigations, which have been carried out by Dr. Earl R. Norris, are primarily in the fields of nutrition and metabolism. An investigation of the vitamin B and vitamin C content of a number of marine algae showed that most of the algae compare very favorably with fruits and vegetables as sources of vitamins. A few of the species tested proved to be as rich a source of vitamin C as lemons. Species of *Porphyra* were the richest source of both vitamin B and vitamin C among the algae examined.

The conditions optimum for the activity of the phosphatases found in many phyla of marine invertebrates have been determined. Enzyme activities occurred in both alkaline and slightly acid solution. The activity of the phosphatases was inhibited by dialysis and restored by the addition of magnesium ions with an optimum concentration between 0.01 and 0.001 molar. The invertebrate phosphatases studied were more heat labile than rat-kidney phosphatase.

In the study of nutritional requirements of salmon, a question arose concerning the ability of the fish to utilize carbohydrate. This led to an investigation of the amylase of the tissues and contents of the digestive tracts of mature fish from each of the five species of Pacific salmon. The optimum hydrogen ion concentration for the amylase was the same for the five species and slightly more alkaline than for phyalin or mammalian pancreatic amylase tested under the same conditions. The amylase activity was relatively low, averaging about one-twentieth that of mammals.

Dr. Anna C. Norris has recently begun an investigation on the carotinoid content in some of the marine invertebrates of the northeast Pacific.

In coöperation with the School of Fisheries of the University of Washington, a study of nutritional requirements of young salmonoid fishes has been carried on for the past four years.

Bacteriology.—The researches of Dr. B. S. Henry and Dr. Erling J. Ordal in marine bacteriology during the past six years have been varied but have had a general continuity in that they have been directed toward an understanding of the physiology of bacteria whether of marine or terrestrial origin.

The effect of decomposition carried on by marine anaerobes in waters polluted by pulp-mill wastes has been investigated, and it has been shown that many bacteria found under such conditions are capable of decomposing the sulfite-waste liquor. Five new species of anaerobes isolated in this work have been described.

Studies on bacterial spores have shown that the vegetative and spore forms of bacteria have only slight differences in their water content but that the great differences found in the relative resistance of these two forms to unfavorable environmental conditions is due in part to the difference in their bound water content.

The distribution of marine aerobes in the Puget Sound area and off the coast of the state of Washington and Vancouver Island has been determined during the past five years. The numbers and types found have been correlated with various factors such as land drainage, tides, temperature, and phytoplankton occurrence. Vertical and regional distribution have also been studied.

The effect of variations in culture media upon the results of bacterial counts of sea water has been investigated. The optimum concentrations of nitrogen and carbon sources, hydrogen ion concentration, incubation temperatures, and other factors were determined.

A detailed study of the utilization of nitrogen compounds by a selected representative group of 15 marine aerobes has been completed. The compounds used included inorganic and organic ammonium salts, amides, amino acids, and cyclic compounds.

It has recently been found that the hydrogen produced from carbohydrates by certain facultative anaerobes indicate that formic acid is the precursor of the hydrogen and that formic dehydrogenase and hydrogenase are constituents of the enzyme-liberating hydrogen from formic acid.

Algae and phytoplankton.—Investigations of the marine algae have consisted primarily of a study of the growth, metabolism, and water relations of these plants, including both the external and the internal factors. The carbohydrates present in kelps, as well as the gaseous contents and pressures, have been determined on a number of individual plants. Efforts by Professor George B. Rigg to extract and demonstrate the presence of "growth substances" in *Nereocystis leutkeana* have proved successful. Considerable data on the ecological aspects of the plants and animals in the intertidal zone on rocky shores have been accumulated and a summary of the findings will appear in one of the symposia of this Congress. A study of the plant communities found in salt marshes and the physical and chemical factors existing in these communities has been in progress during the past several years.

Various specimens of *Zostera marina* from a number of localities along the coast of the state of Washington have been collected to determine if, when, and where the "wasting disease" of *Zostera marina* common in the Atlantic Ocean would make an appearance on the North Pacific Coast. Determination of the relationship between sea-water temperatures and the production and germination of *Zostera marina* has been made.

The problems concerning the phytoplankton have consisted in determining the common species which form the preponderance of the local flora of the San Juan Archipelago and ascertaining the periodicity of these species in the channels and sounds of this region. It was found that the phytoplankton productions are seasonally late in the channels of the San Juan Archipelago but are seasonally comparable in East Sound to other areas in other parts of the world in the same latitude. The vertical distribution of the phytoplankton in the channels is exceedingly irregular, owing to the marked turbulence of the waters caused by tidal currents. Some living diatoms were found at 100 meters, yet they were in excellent physiological condition, having probably been carried down to that depth very recently from well within the photic zone. Attempts have been made to correlate certain environmental factors, such as concentrations of nutrient salts, temperature, and total solar radiation received at approximately sea level, with the phytoplankton production, since it was evident from prior studies that absence of seasonal stratification of the sea water delayed the seasonal beginning of the diatom growth.

During the summer of 1934 the geographical distribution of the phytoplankton in the waters of the east part of the Bering Sea was investigated. None of the predominantly Arctic forms were found, thus giving evidence that the waters of the Bering Sea had their origin in the northern Pacific rather than in the Arctic Ocean. Measurements were likewise made on the seasonal variation in the cell volumes of the dominant diatom species of this area.

Attempts are being made to determine the density of marine phytoplankton populations by the extraction and colorimetric evaluation of the chlorophyll content as a measure of the number of cells per liter of sea water or the cell volume per liter.

Zoölogical studies.—Investigations on the seasonal settlement of marine organisms have yielded important evidence on the life histories, breeding periods, and economic importance of certain wharf pile-inhabiting animals. The information was obtained by suspending blocks of wood in the water at different depths for definite intervals of time over a ten-year period. In this manner the time of spawning and of settling of various organisms was determined.

The life history and developmental stages of copepods occupied the attention of Dr. Martin Johnson prior to his transfer to the Scripps Institution of Oceanography. In the course of these investigations he developed a method which is unique and no doubt of considerable aid to workers in this field.

Migration and settlement of the wood borer, *Limnoria lignorum,* were studied at Friday Harbor from September, 1933, to September, 1934. It was learned that approximately 94 per cent of the settlement took place between January 1 and July 1. Of this settlement approximately 50 per cent occurred between March 1 and May 1. The most active migration of this organism was observed to take place during a time when the temperature was between 7°7 C. and 9°4 C. As an aid to protection of submerged timbers, it is suggested that the most effective time to apply protective paints is at the beginning of the migratory and settling season.

Many studies on the parasites of marine fishes including the ectoparasitic trematodes, the cestodes, and the digenetic trematodes have been conducted. Certain facts in regard to the distribution, life history, and economic effect of the parasites are of fundamental importance in connection with food fishes.

Detailed studies on the shell structure and ligament of clams such as *Cardium corbis* have been undertaken. Such information has a paleontological bearing upon related bivalve mollusks.

Preliminary examinations of the pycnogonids show the desirability of further pursuance of studies on the life history, development, and distribution of this animal group.

Embryological studies on the development of many marine organisms such as crabs, shrimps, clams, and sea cucumbers are being continued.

Several thousand vertical net hauls have been made along the North American coast from the California line to Point Barrow, and in many of the channels, straits, sounds, estuaries, and bays of this region. The results of these hauls are gradually being investigated.

Observations on the San Juan Archipelago avifauna indicate that it consists of many sea birds. These observations have been augmented by analagous ones made in the Puget Sound, British Columbia, and southwestern Alaska areas and at sea for several thousand miles along the North American coast.

About 70 species of shrimp included in eleven genera of six families have been a subject of detailed investigation, a study inaugurated some thirty years ago by Professor Kincaid. Dr. Belle A. Stevens has been preparing taxonomic keys to aid easy identification of the various species by those less familiar with Crustacea than the carcinologists.

A new subspecies of *Lepas pectinata* has been described by Dr. Dora P. Henry. Supplementary descriptions of *L. anatifera, L. fascicularis aurivillii, Scalpellum columbianum,* and *Mitella polymerus* have been published. *L. fascicularis aurivillii* was reported for the first time from the Pacific Ocean.

The sessile barnacles of Puget Sound and adjacent waters have shown certain variations from the typical form of the various barnacles. The associations of the various barnacles, and zones inhabited by them, together with records of a great number of localities in which they occur, have been made. In addition collections of barnacles from scattered localities from Alaska to Lower California have extended the known range of a number of species and disclosed some interesting variations from the typical form in several species.

A preliminary survey of the tunicates of Puget Sound shows this region to be very plentiful both in numbers and in species, and two of the species are probably new.

Publications.—Two series of publications provide outlets for papers. One is the Reprint Series in Oceanography, which consists of reprints of papers appearing in various scientific journals; the other is Publications in Oceanography, which come from the University of Washington Press. The latter series affords a means for the publication of more extensive papers. Contributions in the Reprint Series have reached eighty-seven in number, seventy-two of which have appeared since 1933, while several volumes of the Publications in Oceanography have been completed.

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THE WORK OF THE "DISCOVERY" COMMITTEE IN THE SOUTH PACIFIC OCEAN

By G. E. R. Deacon

During the first few years of the Committee's activity their vessels worked mainly in the Falkland Dependencies and the adjacent Bellingshausen Sea, but since 1931 the scope of the work has been widely extended and observations have been made along the west coast of South America almost as far as the Equator, and across the southern part of the Pacific Ocean as far as the Ross Sea and New Zealand.

The observations along the west coast were made by the R. R. S. *William Scoresby* during the southern winter of 1931, a period of normal meteorological conditions. The Peru Coastal Current was one of the main objects of enquiry, and a report on the current has been published by Gunther (1936). As was expected, the northward movement was found to be stronger near the coast than in the open sea; and under very diverse meteorological and hydrographical conditions there was always evidence of upwelling. In general the upwelling was found to be equally strong off the Chilean and Peruvian coasts; but where local winds were favorable it was particularly intense; both countries appear to have permanent localities of outstanding activity, and these are centers of rich phytoplankton and zoöplankton populations—more fertile than the rest of the coastal water.

A longitudinal section, about 100 miles from the coast, shows that north of 35°–30° S a stratum of poorly saline water, of sub-Antarctic origin, pushes northward at a depth of 200 to 50 meters above highly saline, poorly oxygennated, water of subtropical origin. The movement can be traced as far as 10°–15° S, and since the depths affected by upwelling vary between 40 and 360 meters, both waters of sub-Antarctic and of subtropical origin may be drawn to the surface.

In several localities small-scale, cyclonic, coastal eddies were found, and in 5°–8° S and 14°–16° S, some 200 miles offshore, there was evidence of anticyclonic swirls. The convergence of warmer offshore water with the coast may bring about the heavy mortality associated with the names *"Aguaje"* and *"El Pintor"*; these conditions appear to occur locally, with minor meteorological changes, and are on a lesser scale than the devastating effects of *"El Nino,"* which under the influence of winds of monsoon type may bring hot equatorial water southward along the coast as far as Callao and Pisco.

The deep water observations made during the *William Scoresby*'s voyage have not yet been closely examined, but now, with the interruption of the work at sea, the checking and classification of the hydrographical observations and soundings will proceed more quickly, and the data will soon be published.

The work in the Antarctic and sub-Antarctic regions has been carried out mainly by R. R. S. *Discovery II*. A W-shaped cruise was made from New Zealand to the Magellan Strait in September and October, 1932, voyages west and east near the ice edge in the summer of 1933–34, and an eastward voyage, confined mainly to the Antarctic zone, in February and March, 1938. A brief survey of the hydrography of the Ross Sea was made in January, 1936.

The 1932 sections have been published by Deacon (1937), and some of the work on nutrient salts by Clowes (1938), but most of the material awaits publication within the next few years.

The heaviest water in the South Pacific Ocean was found in the southwestern part of the Ross Sea, with a temperature as low as —1.94° C. and a salinity as high as 34.87‰. It can only be formed as a result of the intensive freezing processes in winter, and it is prevented from sinking down the continental slope into the deep basin to the north by the submarine ridge which joins Cape Adare and King Edward VII Land. Along the foot of the continental slope south of the Pacific Ocean the bottom temperatures and salinities increase from west to east, and the oxygen content of the bottom water decreases along the same path. These changes show that the conditions are determined mainly by the almost circumpolar bottom current that has its origin in the Weddell Sea. The cooling effect of the shelf water appears to be confined mainly to the upper part of the deep current, and, as far as can be seen at present, the shelf water does not become dense enough to join the mixture of deep and bottom waters below the nucleus of the deep current.

The existence of an eastward current of highly saline deep water from the region south of Australia into the Pacific, suggested by Defant(1928), Wüst (1929), Möller (1929), and Sverdrup (1931), was confirmed; and it seems most probable that a large percentage of the water in the current has its origin in the deep currents from the North Atlantic Ocean. As the current crosses the Pacific Ocean it is reinforced in its upper strata by warmer but less saline water which is probably formed by mixing in the tropical and subtropical regions of the ocean; water from the lower part of the current filters away to the north with the bottom current.

The observations made in the different sectors of the Southern Ocean have shown that the latitude of the Antarctic convergence—the northern limit of the Antarctic water at the surface—is determined by the latitude in which the warm deep layer makes a relatively steep climb over the cold bottom layer, and it is believed that the high latitude of the convergence in the eastern part of the Pacific Ocean is due to the decrease in volume of the bottom layer owing to the gradual draining away of the bottom water to the north, as well as to the deflection of the surface and deep currents to the south in the neighborhood of Cape Horn.

Recent observations show that the Antarctic convergence bends toward the south in the region north of the Ross Sea, and in 178° E its latitude is 60° S. In 137° W it bends northward again as far as 53½° S, and the observations made there show that the advance toward the north is caused mainly by the Cape Adar–Easter Island ridge, which deflects the bottom, deep, and surface currents northward.

The results of the survey work carried out by the Committee's vessels have been incorporated by the Hydrographic Department of the Admiralty in their charts and in the Antarctic Pilot. Most attention has been paid to the South Shetland group, between Clarence Island and Adelaide Island. Farther west, between Charcot Island and the Ross Sea, the coast line has not been sighted, but the following points have been reached:

Longitude W	*Latitude S*	*Sounding (in meters)*
81° 55′	70° 34′	580
87° 46′	70° 10½′	1500
102° 48′	70° 20′	2835
129° 16′	70° 25′	3870
143° 35′	71° 25′	4300

A shallow bank with a sounding of only 1309 meters was found in 69° 25′ S to 69° 27′ S between 126° 15′ W and 126° 20′ W. Several lines of soundings have been made in the Ross Sea and its approaches, and a new chart has been made of the Balleny Islands.

APPENDIX

In view of the most unusual character of the salinity distribution in the southwestern part of the Ross Sea, the temperature, salinity, and oxygen data for the deepest station— in 77° 12′.8 S, 170° 05′.3 E, near Ross Island—are given in full.

Depth (meters)	*Temperature* (degrees C.)	*Salinity* ($^0/_{00}$)	*Oxygen content* (cc/liter)
0	—0.49	34.45	7.70
10	—0.53	34.45	......
20	—0.58	34.46	7.62
30	—0.59	34.46	......
40	—0.65	34.46	7.56
50	—0.70	34.49	......
60	—1.39	34.50	6.24
80	—1.73	34.52	......
100	—1.79	34.52	5.93
150	—1.77	34.59	5.88
200	—1.88	34.62	6.02
300	—1.89	34.70	6.01
400	—1.94	34.77	6.02
500	—1.86	34.82	5.82
600	—1.64	34.84	5.94
650	—1.86	34.84	5.77
700	—1.87	34.85	5.91
750	—1.92	34.85	5.94
800	—1.91	34.87	6.03

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THE "SNELLIUS" EXPEDITION IN THE EASTERN PART OF THE NETHERLANDS INDIES, 1929–1930: SURFACE OBSERVATIONS, TEMPERATURE, SALINITY, DENSITY

By S. W. Visser

Continuous records of sea-water temperatures were carried out by means of an electrical thermograph manufactured by Hartmann and Braun. This thermograph had a rigid position up to the end of August, 1929. Then the instrument was suspended in such a way that it could revolve round an axis lying in the direction of the ship's length. In the early part of December a better balancing gave better results. In March, 1930, the suspension was arranged in such a way that the thermograph was freely movable in all directions with the aid of a simple gimbal ring. After that, even in a rough sea, a regular curve was obtained.

The records often showed rapid and irregular variations. These, according to the oceanographer of the expedition, Dr. Hamaker, were caused by the occurrence of temperature differences in the upper layers, which, owing to the turbulence caused by the ship, influenced the records as described. These variations depended upon the suspension of the galvanometer and the state of the sea. After the gimbal ring was applied, the scattering appeared to be greatest when the sea was calmest—and here we meet with the true effect of the steep temperature gradient on calm days.

It appeared that bucket temperatures represent by no means the true surface temperatures. Systematic errors of 0.2° C., occurring in about half the observations, are due to meteorological factors, of which the wind is the most important. The general average of monthly mean temperatures was 28°3 C., being 1°2 higher than that of the air.

A well-defined retardation of the diurnal period in the thermograph records was observed : whereas the maximum occurred at 15 h. for the surface observations, it was found for the thermograph at 16.2 h. within 100 km. from the coast, and even at 18 h. beyond. The reason for this retardation was that the thermograph recorded the temperature at about 1.2 m. below the surface. The annual variation has been deduced by means of all available observations—those of the *Snellius* of Captain K. M. van Weel, and of the Bilt Institute, for an atlas which is not yet published.

We find the expected annual variation with two maxima. In the equatorial belt, 1° N–1° S, the period is fairly regular, with maxima at the end of April and of November. To the north and to the south these maxima approach the epochs of the solstices of the hemisphere concerned. The minima occur very constantly in the early part of February and the middle of August. Whereas the variations of the maximum are small (28°1 to 28°8), those of the maximum are much larger (25°6 to 28°0) and behave contrarily in the two hemispheres. We meet the lowest temperatures in August and in the Banda Sea (less than 26°). There is a contrast between the two hemispheres, principally owing to the opposing features of the seas investigated : the open Pacific Ocean in the Northern Hemisphere, the basin of the Banda Sea in the Southern. Especially do we see that the amplitudes are much smaller in the open ocean than in the inland seas.

The salinity of the surface water was determined by means of the common chlorine titration method. A number of German observations and those executed by van Weel were also used. The general salinity frequency is obviously skew, the lower values being due to influences of the coasts; even beyond 100 km. these influences have not wholly disappeared. High salinities are scanty. Values above 34.6 scarcely occur.

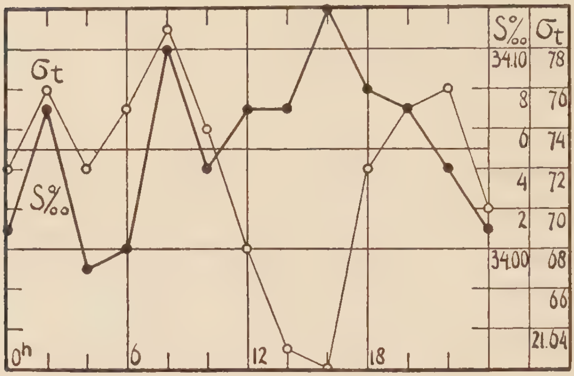


Fig. 1. Salinity and density of the surface water.

The diurnal variation is determined only for distances beyond 100 km. from the coast.

	0^h	2^h	4^h	6^h	8^h	10^h	12^h	14^h	16^h	18^h	20^h	22^h	Mean
Salinity S‰	34.0	34.1	34.0	34.0	34.1	34.0	34.1	34.1	34.1	34.1	34.1	34.0	34.05
Density σ_t. .	21.7	21.8	21.7	21.8	21.8	21.7	21.7	21.6	21.6	21.7	21.8	21.8	21.73
Temperature	27.8	27.8	27.8	27.8	28.0	27.9	28.0	28.2	28.2	28.0	28.0	27.9	27.96

There is an obvious correlation between salt content and temperature, rising and falling simultaneously, the minima being reached at 3 h., the maxima at 15 h. The variations of S and σ_t are small and irregular. At night they run parallel. The strong decrease in density during the daytime must be ascribed to the temperature maximum, the increase of salinity to evaporation.

The observations do not suffice for deducing particulars of the annual variations. The character of the variations may be deduced for average season values in different regions, but even then the figures are only complete for the minority (9 out of 22). A well-established diagram based in large part upon monthly figures could be deduced for the western part of the East Java Sea. The most striking fact is the great change from May to August, during the east monsoon, when cold and salt water flows in from the east. During the change of monsoon, September to November, the salinity remains constant but the temperature rises. Then the west monsoon, December to February, conveys warm water of decreasing salt content from the Java Sea, and during the change of monsoon, March to May, the salinity is variable, but remains low whereas the temperature tends to rise.

Concerning the geographical distribution, both van Weel and Schott have drawn isohalines in the Archipelago for about the same periods. Though based upon the same material, the curves of these two investigators differ in many respects. The *Snellius* researches may clear up matters. Four salinity maps for the four seasons have been drawn and the same effects found for the Java Sea are present in the strong curvatures and great changes of the isohalines.

During December to February, water of low salinity is carried from the Java Sea and from the north to Makassar Strait in an eastern direction up to the east side of the Saleyer Islands.

From March to May the salinity is generally low: values of more than 34 are found only in the Pacific Ocean and the eastern Celebes Sea. The salt content decreases steadily from north to south and from east to west.

In the east monsoon months, June to August, the salinity is high in a large part of the Archipelago, exceeding 34. The highest value, beyond 34.5 and even as great as 34.75, is present in the seas between Halmahera, Ceram, and New Guinea, carried on, as stated by van Weel, by the northern branch of the South Equatorial Current.

From September to November the salinity is still high, exceeding 34.5 in one uninterrupted region from the Pacific via the Banda Sea to the Indian Ocean. The isohalines show similar features in both changes of monsoon seasons, April and October, but in the latter season the salinity is about 1 per cent higher.

RECENT CURRENT MEASUREMENTS IN WATERS OF THE DUTCH EAST INDIAN ARCHIPELAGO

By L. Lek

The Dutch East Indian Archipelago is very closely related to the Pacific Ocean, and for that reason it may be of interest to note a few results of the current measurements made by the *Snellius* expedition at anchor stations. The expedition worked during 1929 and 1930 in the eastern part of the archipelago, and had, in addition to the hundreds of ordinary oceanographical stations, seven anchor stations. The anchor stations were situated mainly in the important straits, which afforded an opportunity for the study of the exchange of water between the basins and the Indian Ocean and the Pacific Ocean. In the deeper layers of all stations current measurements were taken by means of the Ekman repeating current meter and the Ekman strong current meter. Operations were performed every two hours for a period of twenty-four hours. The observation times for surface layer measurements were: for station 39, 62 hours; station 135, 89 hours; station 253, 82 hours; station 308, 53 hours; station 317, 51 hours; station 354, 35 hours; station 364, 24 hours, the intervals being of one hour. The surface current observations were taken by means of a reelingslog. Besides the current measures, measurements of temperature, salinity, and oxygen content were taken at regular intervals in the various depths. These observations proved the presence of important internal waves. On different occasions we found internal waves with an amplitude of 15 meters, but at this time only the current measurements will be discussed.

The stations situated in the straits show great strength of current; for example, at Station 253, the tidal stream ellipse data of which are given in table 1. The first column gives the depth, the second the direction of the maximum current, the third its strength, the fourth its phase in lunar hours, the fifth the ratio of the minor to the major axes of the ellipse, and the sixth the sense of the current. The upper part shows the result of the diurnal tide, the lower those of the semidiurnal tide.

TABLE 1

Data from Station 253

Depth	Direction of maximum current	Velocity	Phase	Ratio of minor to major axes	Sense of the current
			Diurnal		
0 m.	N 0°.8 E	21.8	10.0	0.431	Cum sole
50	N 12°.5 E	21.6	8.3	0.000	Alternating
100	N 41°.5 W	13.2	17.1	0.546	Contra solem
200	N 36°.5 W	14.9	15.8	0.181	Contra solem
350	N 25°.5 W	9.0	18.0	0.456	Cum sole
500	N 82°.5 E	7.8	0.2	0.000	Alternating
			Semidiurnal		
0 m.	N 2°.5 W	13.6	2.6	0.566	Contra solem
50	N 14°.0 E	26.1	2.8	0.391	Contra solem
100	N 0°.5 W	35.1	4.0	0.348	Cum sole
200	N 24°.5 E	44.2	4.0	0.143	Cum sole
350	N 16°.0 E	24.8	4.8	0.242	Contra solem
500	N 6°.0 W	22.3	5.3	0.498	Contra solem

The diurnal tidal current shows a steady decrease of amplitude by increasing depths and very irregular phase values. The semidiurnal tide gives a completely different picture; here the tidal current increases its strength from 13.6 cm/sec. on the surface to a maximum of 44.2 cm/sec. at a depth of 200 meters, the phase being retarded regularly with increasing depth. This example is not an exception, but occurs frequently. Generally speaking, the amplitude of the semidiurnal tide was found to be greater than that of the diurnal tide. The diurnal phases are irregular, whereas the semidiurnal phases regularly increase with depth.

Besides the diurnal and semidiurnal waves, waves with shorter period and significant amplitudes were found, the period lying between 5 and 7 lunar hours. These occur not only for current measurements, but also for temperature observations. Taking the average value of the 69 short-period waves, we have found as an average period, 6.1 lunar hours, which seem to point to a superior harmonic of the semidiurnal tide. Had there been shorter intervals of the current measurements, we might have found a period of 6 hours with more precision. The theoretical value of the ratio of the minor to the major axes of a tidal ellipse is $S = \frac{2 \omega \sin \delta T.}{2 \pi}$ Thus on the equator, where $\sin \delta = 0$, the ellipse is reduced to a straight line and the current is alternating. Now it happens that most of the *Snellius* anchor stations were very close to the equator, and the question arises, How do the ratio of the current ellipses comply with the theory? We had at our disposal 41 diurnal and 44 semidiurnal ellipses, of which 29 were cum sole, 27 contra solem, and 28 alternating. If ellipses with an axis ratio of <0.15 are taken as alternating, we find an equal distribution which may result from chance. It must, however, not be forgotten that this formula is only valid for the open ocean, and that the currents in the narrow straits where the anchor stations were made were subject to friction, which has an influence not to be underestimated on the shape of the tidal-stream ellipse.

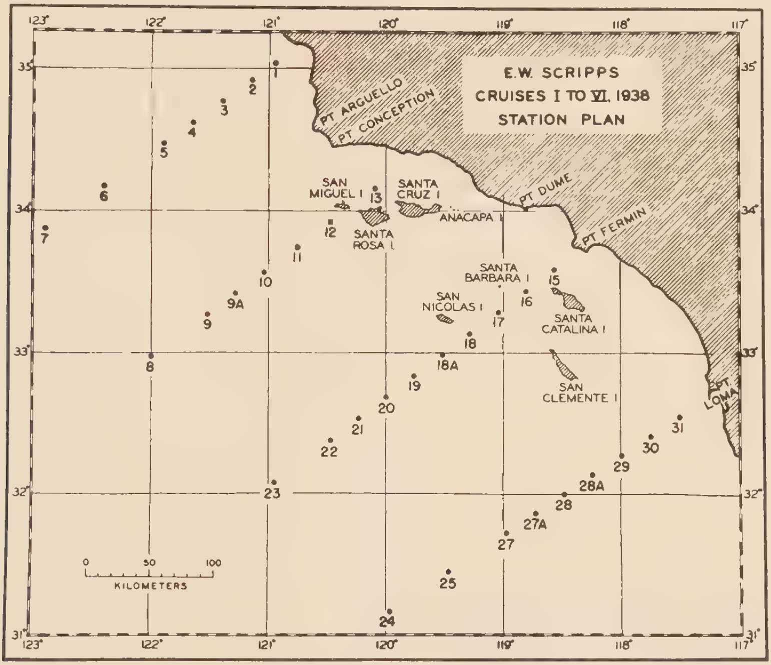
From the data collected at anchor station, the following water movements can be deduced. Surface water from the Pacific flows in a 50-meter thick layer through Halmaheira Sea to the Ceram Sea, where it curves and flows through Lifamatola Strait to the Molukken Sea. There is also another inflow of Pacific surface water to the Banda Sea through the Arafoera Sea. The Indian Ocean also contributes to the renewal of the surface layer of the Archipelago through Sawoe Strait, and at the depth of 1000 meters we found a return flow from the Sawoe Sea into the Indian Ocean. It seems that a part of the surface layer of the Celebes Sea flows through Sibutu Strait to the Sulu Sea and another part goes through Makassar Strait to the Java Sea. The currents in the deeper layers show a quite different picture. The Halmaheira Sea is very shallow and the deeper Pacific water has to pass through the Molukken Sea to get into the Boeroe Sea. The deeper layer of the Banda Sea gets its supply from the Flores Sea.

However, not until we have complete maps of the distribution of temperature, salinity, and oxygen content, as well as the dynamic topography of those seas shall we be able to draw a map showing details of circulation.

CHARACTER OF THE CURRENTS OFF SOUTHERN CALIFORNIA

By Richard H. Fleming

Within an area extending from 31° N to 35° N and approximately 150 miles to sea, systematic oceanographic observations were carried out by the Scripps Institution of Oceanography on three cruises in the spring and early summer of 1937, and six cruises in 1938. The general locations for the collection of data are shown in figure 1. Because of stormy weather and unfavorable conditions it was sometimes impossible to occupy all these stations. The investigations in 1937 were carried out with the coöperation of the California State Fisheries Laboratories of the Division of Fish and Game, and their vessel, the *Bluefin,* was used to make the three cruises (Sverdrup and Fleming, in press). In 1938 the *E. W. Scripps* was placed in commission and made six cruises at two-months intervals (Sverdrup and staff, in press). The 1937 investigations showed that the currents associated with the distribution of density were largely within the upper 500 meters, and therefore in 1938 the observations were usually restricted to the upper 600 meters. Besides temperature observations and salinity determinations, analyses for the content of dissolved oxygen were carried out on all water samples collected. In addition, phosphate determinations were made on the first three cruises in 1938 and the program was enlarged to include phytoplankton collections and zoöplankton samples.


E.W. SCRIPPS
CRUISES I TO VI. 1938
STATION PLAN
123°
122°
121°
120°
119°
118°
117°
35°
34°
33°
32°
31°
PT ARGUELLO
PT CONCEPTION
PT DUME
PT FERMIN
PT LOMA
SAN MIGUEL I
SANTA CRUZ I
ANACAPA I
SANTA ROSA I
SANTA BARBARA I
SAN NICOLAS I
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KILOMETERS

Fig. 1. Station plan for the investigations carried out by the *E. W. Scripps* in 1938. The same general plan was followed in 1937 by the *Bluefin.*

The present discussion of the circulation will be based largely upon the 1938 observations, as these cover the entire year. Within the area covered by these studies the pattern of flow at and near the surface is very complicated.

The reasons for this will be dealt with later. However, the general features may be described as follows. In the offshore area there is generally a transport to the south or southeast which represents the eastern portion of the California Current. Between the California Current and the coast there is commonly a flow to the north, termed the California Counter Current. At least a part of this current usually turns inshore and flows to the south again along the coast. During the spring and early summer months the Counter Current may disappear at the surface, but at lower levels the northward transport near the coast persists throughout the year. Figure 2 shows the generalized pattern of flow at the surface.

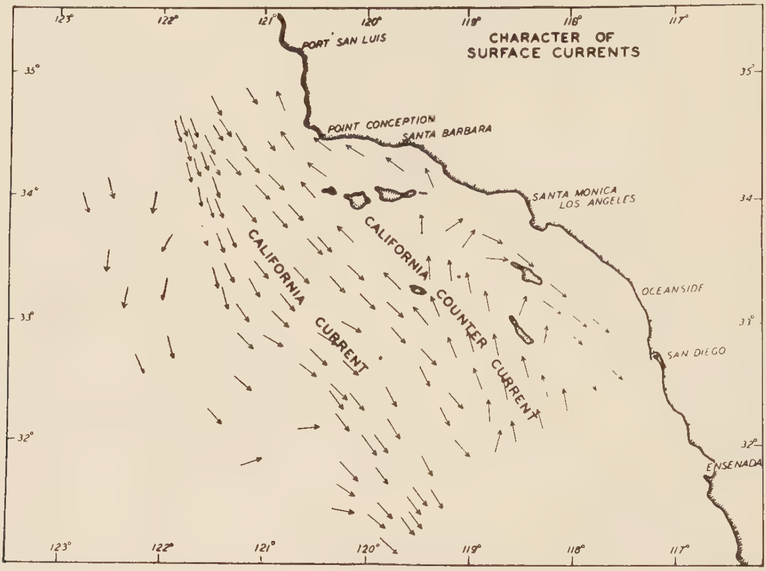

Fig. 2. Generalized pattern of surface flow off the coast of Southern California and names applied to the currents.

The surface currents, associated with the distribution of density observed on the six cruises in 1938, are shown in figures 3 to 8. It can readily be seen that the Counter Current has its greatest development during the winter months, when it extends northward as far as observations were obtained (figs. 3 to 8). During the spring months (fig. 4) the Counter Current apparently disappears entirely at the surface under the influence of the northwest winds, which are strongest at this time of year. During the summer and autumn there is a gradual reëstablishment of surface flow to the north. It is striking that the pattern of flow in the offshore area within the California Current is extremely irregular. In some cases there are bands of high velocity, as is shown in figure 5, and in all cases where relatively complete series of observations were obtained, there is evidence of the presence of eddies. Lack of observations extending farther west and south make it impossible to determine the nature of the inflow from the west, particularly in the southwestern portion of the area investigated, which is shown on most of the charts.

Between the California Current and the Counter Current there is a dynamic low. Examination of figures 3 to 8 shows that this trough usually extends southward from the area off Point Conception. During the spring months

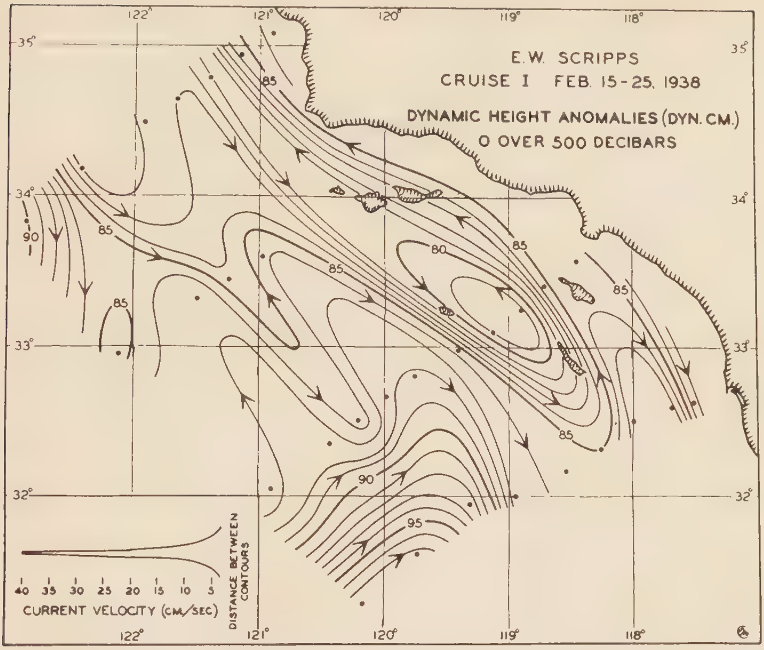
E.W. SCRIPPS
CRUISE I FEB. 15-25, 1938
DYNAMIC HEIGHT ANOMALIES (DYN. CM.)
0 OVER 500 DECIBARS
122°
121°
120°
119°
118°
35°
34°
33°
32°
85
90
80
95
DISTANCE BETWEEN CONTOURS
40 35 30 25 20 15 10 5
CURRENT VELOCITY (CM/SEC)

Fig. 3. Dynamic height anomalies in dynamic centimeters, 0 over 500 decibars. February 15–25, 1938.

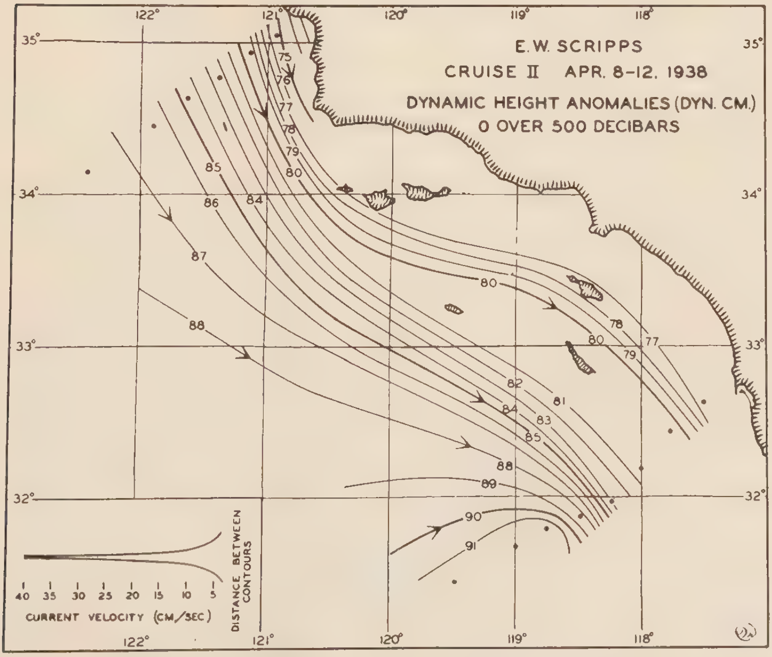
E.W. SCRIPPS
CRUISE II APR. 8-12, 1938
DYNAMIC HEIGHT ANOMALIES (DYN. CM.)
0 OVER 500 DECIBARS
122°
121°
120°
119°
118°
35°
34°
33°
32°
75
76
77
78
79
80
81
82
83
84
85
86
87
88
89
90
91
DISTANCE BETWEEN CONTOURS
40 35 30 25 20 15 10 5
CURRENT VELOCITY (CM/SEC)

Fig. 4. Dynamic height anomalies in dynamic centimeters, 0 over 500 decibars. April 8–12, 1938.

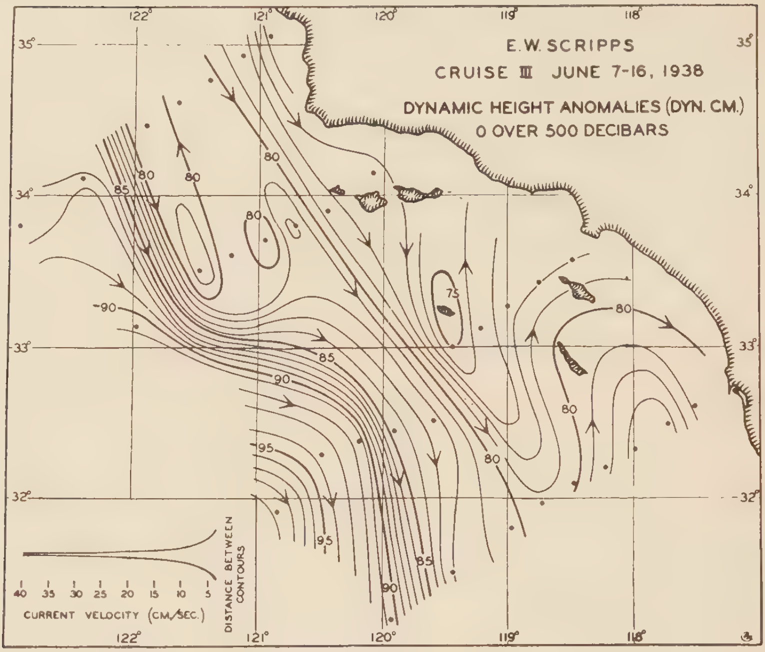
E.W. SCRIPPS
CRUISE III JUNE 7-16, 1938
DYNAMIC HEIGHT ANOMALIES (DYN. CM.)
0 OVER 500 DECIBARS
122°
121°
120°
119°
118°
35°
34°
33°
32°
80
85
90
95
75
40 35 30 25 20 15 10 5
CURRENT VELOCITY (CM/SEC.)
DISTANCE BETWEEN CONTOURS

Fig. 5. Dynamic height anomalies in dynamic centimeters, 0 over 500 decibars. June 7–16, 1938.

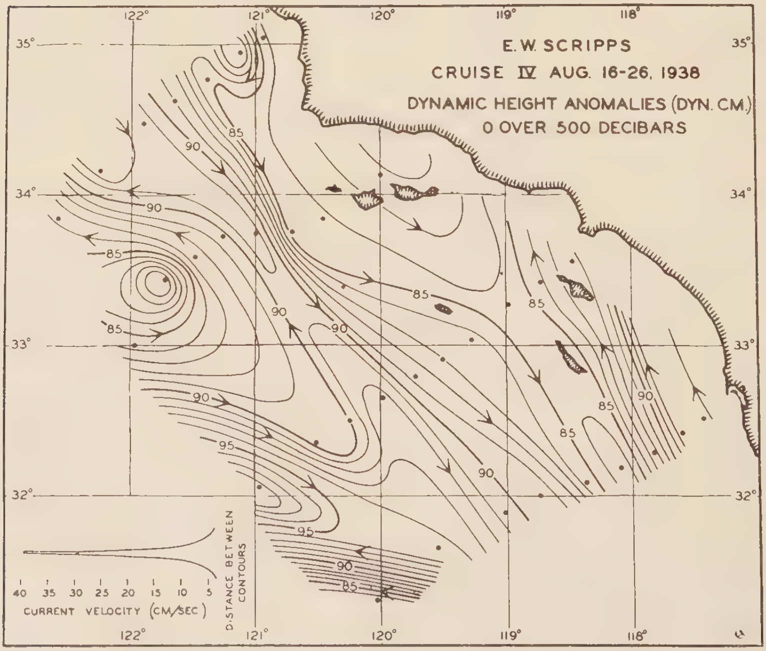
E.W. SCRIPPS
CRUISE IV AUG. 16-26, 1938
DYNAMIC HEIGHT ANOMALIES (DYN. CM.)
0 OVER 500 DECIBARS
122°
121°
120°
119°
118°
35°
34°
33°
32°
85
90
95
40 35 30 25 20 15 10 5
CURRENT VELOCITY (CM/SEC.)
DISTANCE BETWEEN CONTOURS

Fig. 6. Dynamic height anomalies in dynamic centimeters, 0 over 500 decibars. August 16–26, 1938.

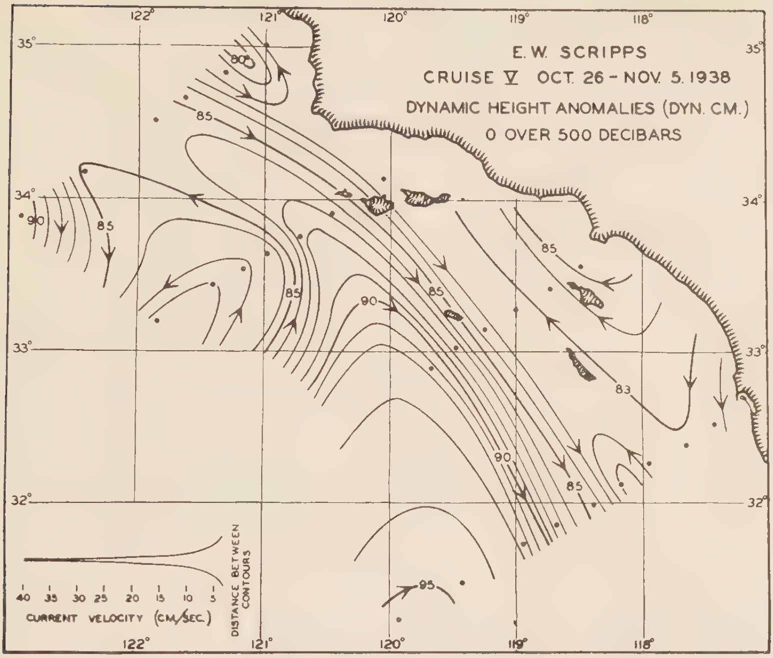
E.W. SCRIPPS
CRUISE V OCT. 26 - NOV. 5. 1938
DYNAMIC HEIGHT ANOMALIES (DYN. CM.)
0 OVER 500 DECIBARS
122°
121°
120°
119°
118°
35°
34°
33°
32°
80
85
90
83
95
40 35 30 25 20 15 10 5
CURRENT VELOCITY (CM./SEC.)
DISTANCE BETWEEN CONTOURS

Fig. 7. Dynamic height anomalies in dynamic centimeters, 0 over 500 decibars. October 26–November 5, 1938.

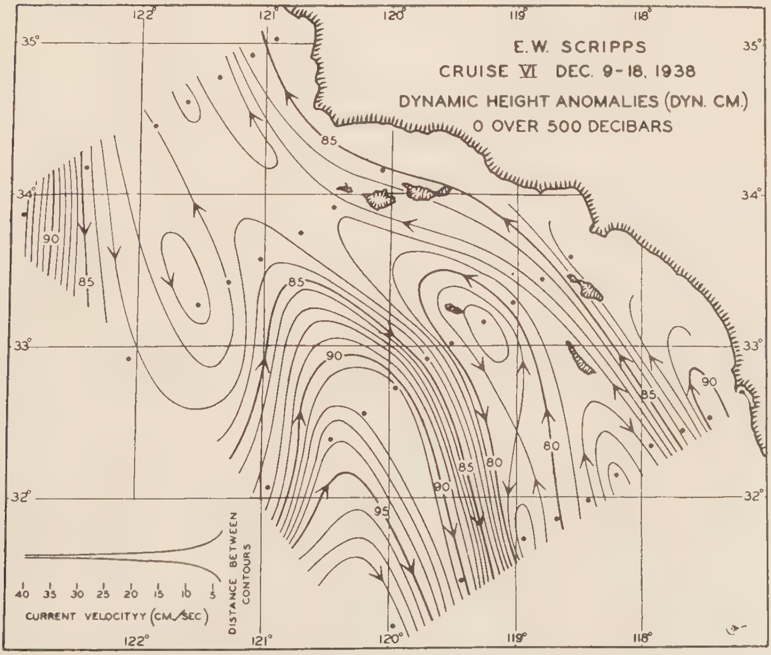
E.W. SCRIPPS
CRUISE VI DEC. 9-18, 1938
DYNAMIC HEIGHT ANOMALIES (DYN. CM.)
0 OVER 500 DECIBARS
122°
121°
120°
119°
118°
35°
34°
33°
32°
85
90
80
95
40 35 30 25 20 15 10 5
CURRENT VELOCITYY (CM./SEC.)
DISTANCE BETWEEN CONTOURS

Fig. 8. Dynamic height anomalies in dynamic centimeters, 0 over 500 decibars. December 9–18, 1938.

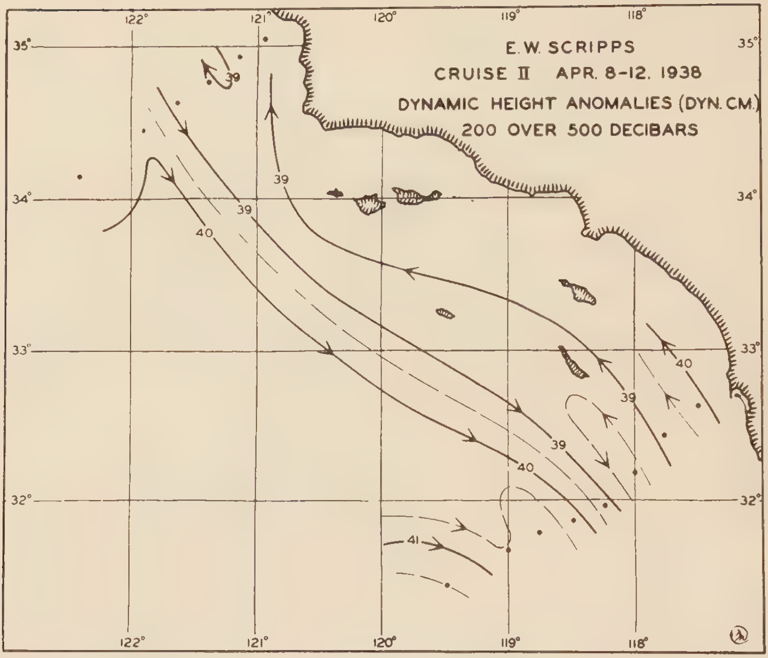
E.W. SCRIPPS
CRUISE II APR. 8-12. 1938
DYNAMIC HEIGHT ANOMALIES (DYN. CM.)
200 OVER 500 DECIBARS
122°
121°
120°
119°
118°
35°
34°
33°
32°
39
40
41

Fig. 9. Dynamic height anomalies, 200 over 500 decibars. Contour interval 0.5 dynamic centimeters. April 8–12, 1938.

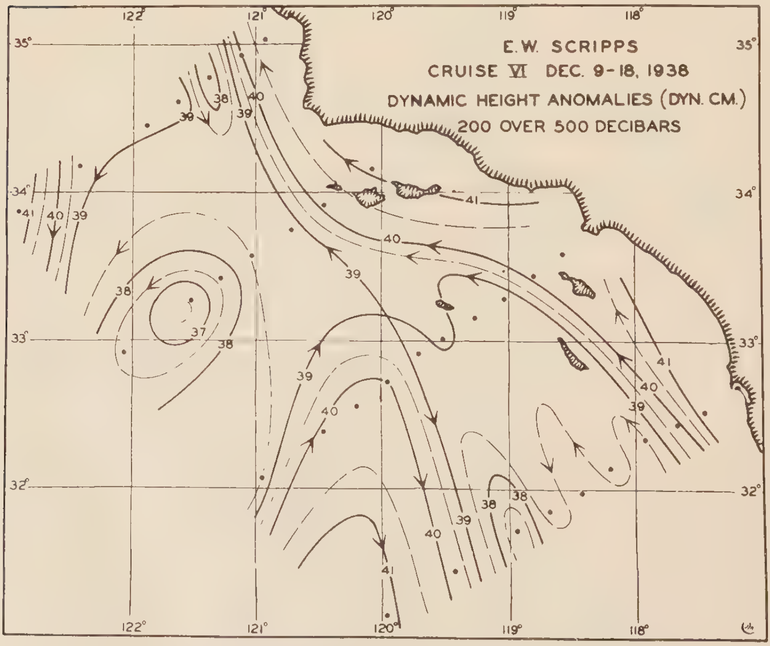
E.W. SCRIPPS
CRUISE VI DEC. 9-18, 1938
DYNAMIC HEIGHT ANOMALIES (DYN. CM.)
200 OVER 500 DECIBARS
122°
121°
120°
119°
118°
35°
34°
33°
32°
37
38
39
40
41

Fig. 10. Dynamic height anomalies, 200 over 500 decibars. Contour interval 0.5 dynamic centimeters. December 9–18, 1938.

this trough moves in toward the coast and corresponds to the zone of active upwelling which occurs at this time of year. In the southern part of the area the contours turn on themselves and indicate that at least part of the surface water in the Counter Current is from the trough which has turned inshore and to the north. Even when there is no indication on the chart of such a flow (fig. 6), the character of the surface water in the Counter Current indicates that it is related to that found in the offshore portion of the trough which has flowed farther to the south before turning north.

On the basis of the pattern of flow it is possible to designate three zones within which the conditions are more or less uniform. First, there is an Offshore Zone, corresponding to the California Current, where the surface temperatures are relatively high and the salinity low, and where the convection layer is relatively thick. Second, there is the Trough Zone, within which the surface temperatures are low and the salinity high, as would be expected from the effects of upwelling. In this zone the convection layer is very thin or may be entirely absent. Third, there is the Counter Current or Coastal Zone, which is characterized by temperatures approximately the same as those in the offshore water, but in which the salinity is intermediate between that of the other two zones and the convection layer is rather thin. Because of the shifts in the currents the conditions encountered at any location may show marked changes in the course of the year which are not related to local climatic variations.

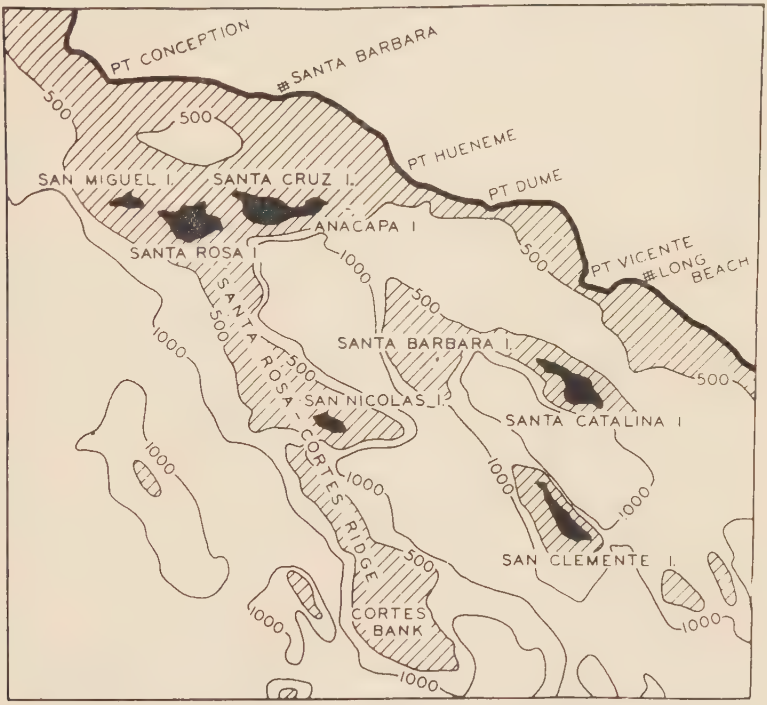
PT CONCEPTION
SANTA BARBARA
500
500
PT HUENEME
SAN MIGUEL I.
SANTA CRUZ I.
PT DUME
ANACAPA I
SANTA ROSA I
1000
500
PT VICENTE
LONG BEACH
SANTA ROSA
500
1000
500
SANTA BARBARA I.
500
SAN NICOLAS I.
SANTA CATALINA I
1000
CORTES RIDGE
1000
1000
1000
500
SAN CLEMENTE I.
CORTES BANK
1000
1000
1000

Fig. 11. Outstanding features of the submarine topography off Southern California. Depths in meters. (After Sverdrup and Fleming.)

The currents associated with the distribution of density are largely restricted to the upper layers and most of the flow as described above occurs in the first 100 meters. At a depth of 200 meters we find a somewhat different pattern. Offshore there is still some indication of transport to the southeast, but the northerly transport near shore is much more conspicuous than at shallower depths. The latter has been termed the deep Coastal Current and is a part of the Counter Current. It may be seen from figures 9 and 10 that the northward-flowing Deep Coastal Current extends farther offshore and that it persists even during the spring months when there is no northward transport at the surface.

The pattern of flow within the area covered by these investigations is apparently rather permanent, but at present the available data do not permit us to account completely for the nature of the flow. The southeasterly flow offshore is part of the California Current and is therefore part of the North Pacific gyral, which is probably maintained by large-scale climatic agencies. The bands of high velocities sometimes encountered in this current have been shown by Sverdrup (1938) to be associated with the local northwest winds and the resultant upwelling. The fact that the Counter Current system persists in the absence of southerly winds indicates that it may be somewhat similar in character to the inshore countercurrent found on the eastern coast of the United States. The topography of the area and the shape of the coast line undoubtedly play important parts in determining the pattern of flow. At a depth of 500 meters there is a peninsula extending south-southeast from the Channel Islands (figure 11). Even at shallower depths this peninsula is almost continuous and consequently the flow to the north must take place outside this ridge or turn on itself within the submarine embayment. It is characteristic of the winds that they are strong north of Point Conception and outside of

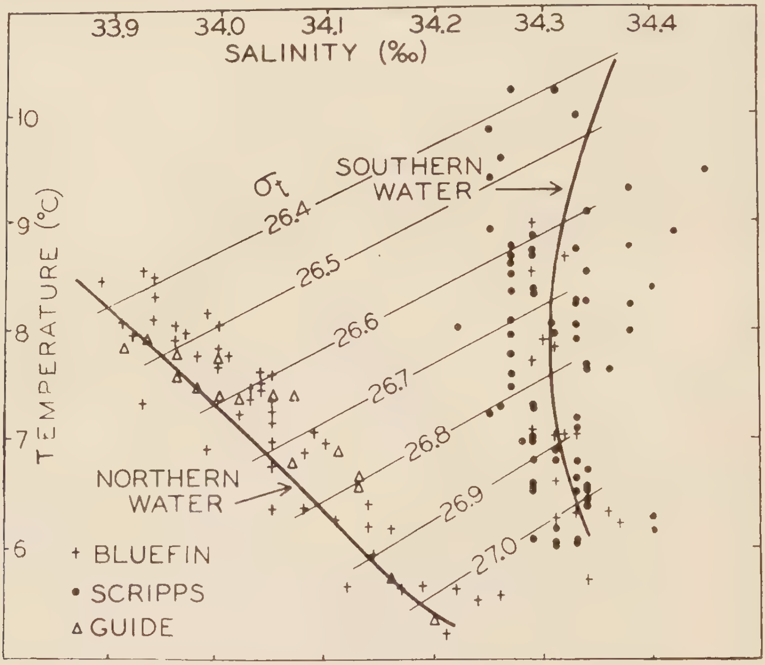

Fig. 12. Scatter diagram showing the temperature and salinity observations used to define the characteristic T-S curves from Northern and Southern Water. (After Sverdrup and Fleming.)

the Santa Rosa-Cortes ridge. Consequently the flow between this ridge and the shore cannot be markedly affected by the local winds. This may, in part at least, account for the fact that off southern California the Counter Current can persist at the surface for the greater part of the year. However, at and beyond Point Conception the strong northwest winds oppose the northward flow and the water of the Counter Current may be forced to flow inshore and to the south.

The area covered by these investigations is one of rather large lateral differences in the distribution of properties. Part of these must be attributed to the gradients associated with the currents, and, near the surface, the upwelling contributes to the differences. However, even at lower levels marked gradients are found and these are due to the differences in the character of the offshore water of the California Current and the water of the Deep Coastal Current. At any temperature less than 10° the water of the Deep Coastal Current has a higher salinity and lower oxygen content. On the basis of the observations in 1937 and earlier collections, T-S curves, characteristic of the offshore water (indicated as Northern Water), and inshore water (indicated as Southern Water), were constructed (fig. 12). T-S curves for virtually all stations correspond to either of these two curves or will fall between them. On the assumption that mixing takes place along σ_t surfaces, it is possible to construct a diagram showing the percentage of Southern Water in any water sample on

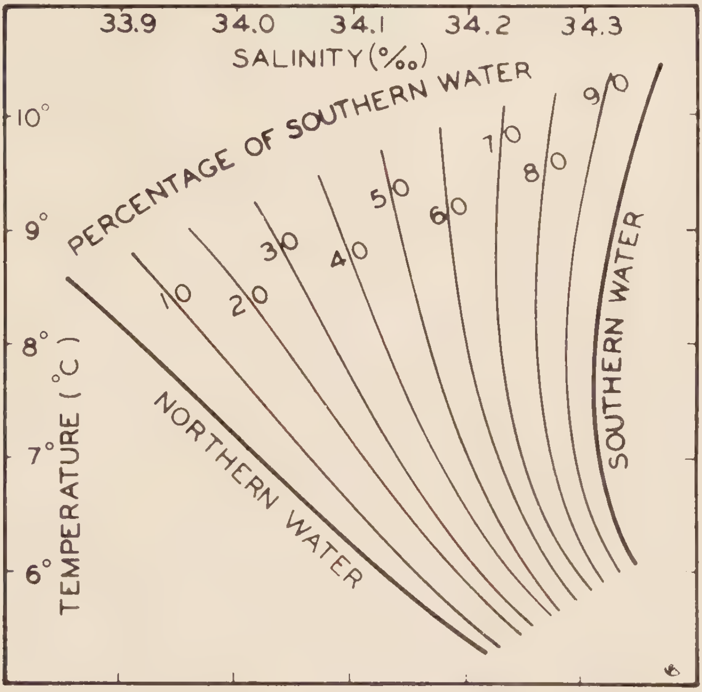

Fig. 13. Diagram showing the T-S curves of water containing various percentages of Southern Water. This diagram is also used to determine the percentage of Southern Water in any water sample of known temperature and salinity. Constructed on the assumption that mixing between the extreme types takes place along σ_t surfaces. (After Sverdrup and Fleming.)

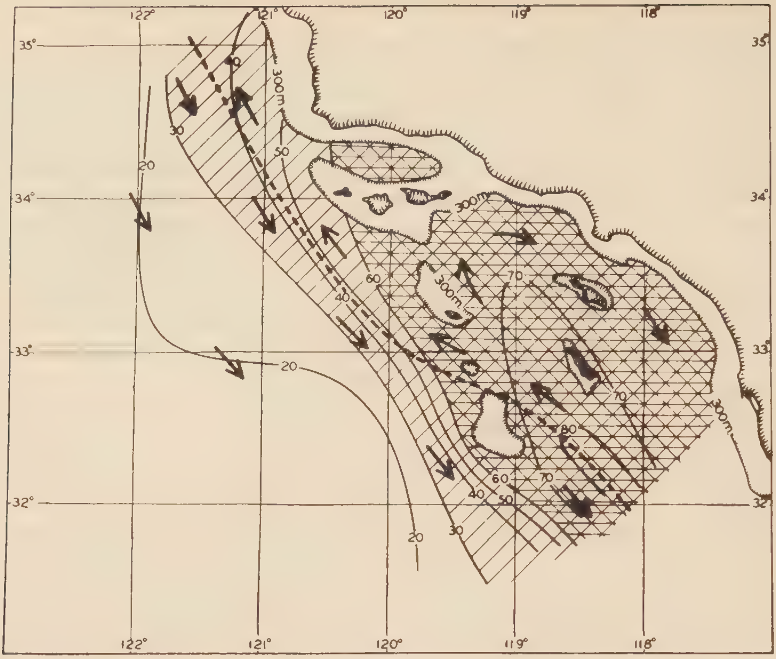
122°
121°
120°
119°
118°
35°
34°
33°
32°
300m
20
30
40
50
60
70
80

Fig. 14. Chart showing the percentage distribution of Southern Water between 200 and 400 meters. Averages of two cruises in 1937. Arrows indicate the direction of flow. (After Sverdrup and Fleming.)

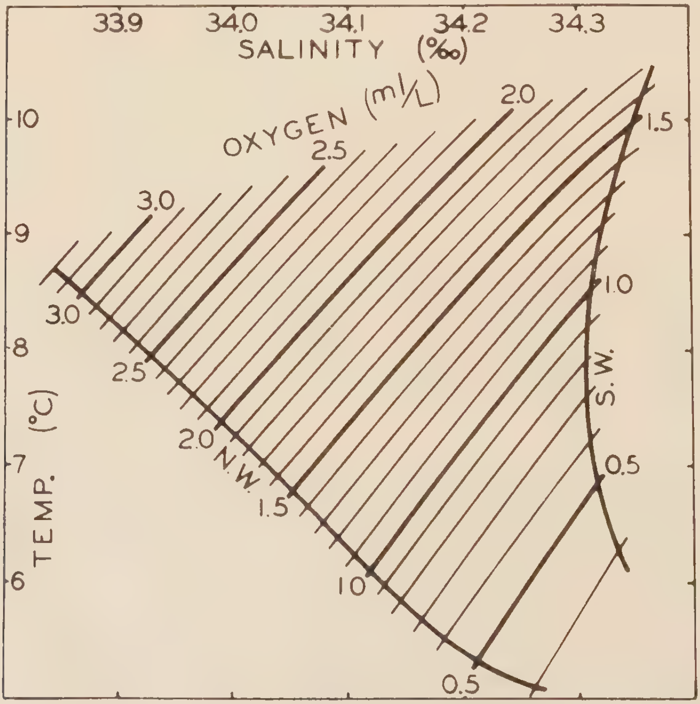

Fig. 15. Diagram showing the "normal" oxygen content of Northern and Southern Water, and mixtures of the two, as a function of the temperature and salinity. Mixing of the extreme types is assumed to take place along σ_t surfaces. (After Sverdrup and Fleming.)

the basis of its temperature and salinity (fig. 13). In this way, profile and charts were constructed representing the distribution of the percentage of Southern Water. These showed that there was a very good regional pattern of distribution of the two types of water except where it was modified by eddies. An example of the horizontal pattern is shown in figure 14. From this it can be seen that within the Counter Current system the percentage of Southern Water decreases along the line of flow. On the other hand, the content of Southern Water increases along the line of flow in the southerly current in the offshore area. As the oxygen content of the Northern and Southern Waters differs appreciably it is possible to prepare a diagram (fig. 15) which shows the "normal" oxygen content of mixtures of the two water masses, assuming, first, that mixing takes place along σ_t surfaces, and second, that there is no consumption. Comparison of the "normal" oxygen contents and the observed quantities showed that consumption does take place along the line of flow (fig. 16).

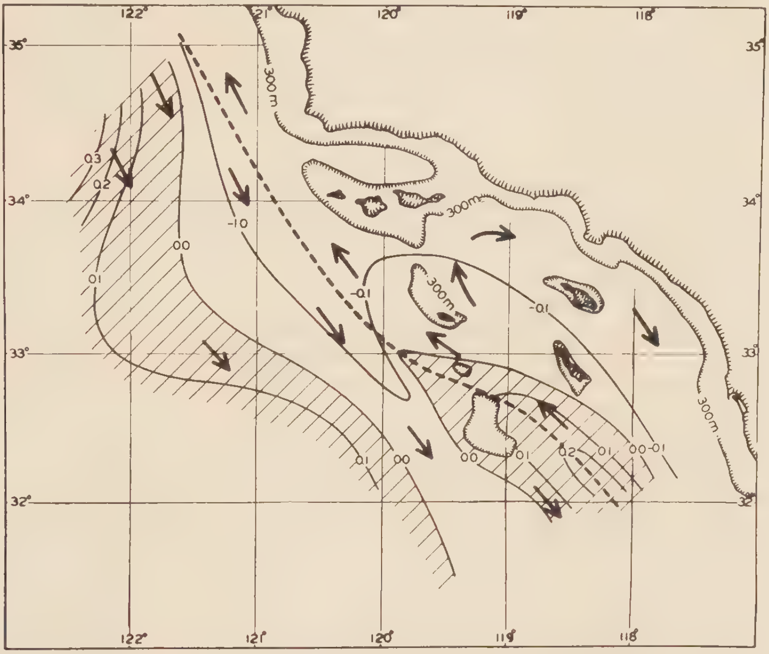

Fig. 16. Chart showing the distribution of oxygen anomalies between 300 and 400 meters. Average of two cruises in 1937. Arrows indicate the direction of flow. (After Sverdrup and Fleming.)

A detailed examination of the 1937 data has been made and on the basis of the distribution of Southern Water and the velocity it was possible to compute the lateral coefficient of eddy diffusivity, which gave values of about 2×10^6 cm^2/sec. From a study of the oxygen anomalies, the total oxygen consumption was computed to be between 1.1 and 2.2 liters per day in a water column of one square meter cross section extending from 50 meters to a depth of 700 meters. This corresponds to a minimum value for the production in the upper 50 meters of between 9.8 and 19.6 grams per square meter per day of wet plankton.

The very active lateral mixing which takes place in this area can readily be determined because of the differences in the properties of the water. This mixing is brought about by eddies of variable dimensions, some of which are as much as 50 kilometers in diameter. These frequently show up on the charts, not only of dynamic topography, but also those showing the distribution of properties. It is of interest to note that the existence of these eddies is confirmed by studies of the distribution of plankton. Within the upper layers the eddies may contain types and quantities of plankton altogether different from those in the water surrounding them. Frequently, eddies composed of Counter Current water were found in the offshore area, and in a few places eddies of offshore water were found in the coastal area.

In conclusion, it is of interest to consider the relation of the southward flow in the offshore area to that of the California Current as a whole. Examination of the 1937 data showed that the southerly transport within the area of these investigations could not represent more than about 10 or 20 per cent of the bulk of the transport of the California Current.

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SVERDRUP, H. U. and staff
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[Contribution from the Scripps Institution of Oceanography, New Series, No. 103].

THE GULF OF CALIFORNIA: PRELIMINARY DISCUSSION OF THE CRUISE OF THE "E. W. SCRIPPS" IN FEBRUARY AND MARCH, 1939

By H. U. Sverdrup

Between February 13 and March 19, 1939, the *E. W. Scripps,* the research vessel of the Scripps Institution of Oceanography, occupied 53 oceanographic stations in the Gulf of California, located on a number of lines across the Gulf. The work started off Cape San Lucas and the first line of stations was run between Cape San Lucas and Mazatlán. The other lines followed in succession from south to north, except that the last two stations were worked in the Ballenas Channel between the islands Angel de la Guardia and San Lorenzo and the peninsula (see fig. 1). By means of a sonic depth finder about 2500 soundings were made at distances which on an average were less than one mile apart. At all stations temperatures were observed and water samples collected between the surface and the bottom for determination of salinity, oxygen, and occasionally other chemical characteristics. Phytoplankton samples were obtained at seven different levels between the surface and 60 meters, vertical hauls for zoöplankton were made between 200 meters and the surface, and bottom samples were procured. Between March 18 and 25, 1939, the U. S. S. *Bushnell* occupied nine oceanographic stations between Balboa, C. Z., and San Diego, California, five of which were across the entrance to the Gulf. At these stations temperatures were observed and water samples collected for determination of salinity and oxygen.

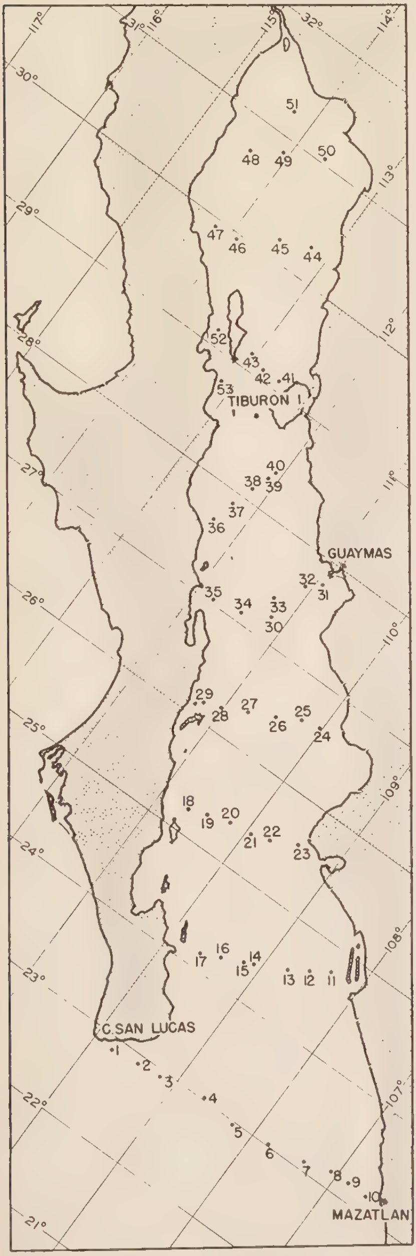

Fig. 1. Location of stations on the *E. W. Scripps* cruise in the Gulf of California, February 13–March 19, 1939.

In the following only the preliminary results relating to distribution of temperature, salinity, and oxygen will be discussed.

The distribution of temperature in the Gulf of California is best represented by means of a series of vertical sections across the Gulf (fig. 2). The left-hand section in the figure is the most southerly, between Cape San Lucas and Mazatlán, and the right-hand top section is the most northerly, south of Tiburon Island. The two sections shown in the bottom right-hand corner represent one from Tiburon Island

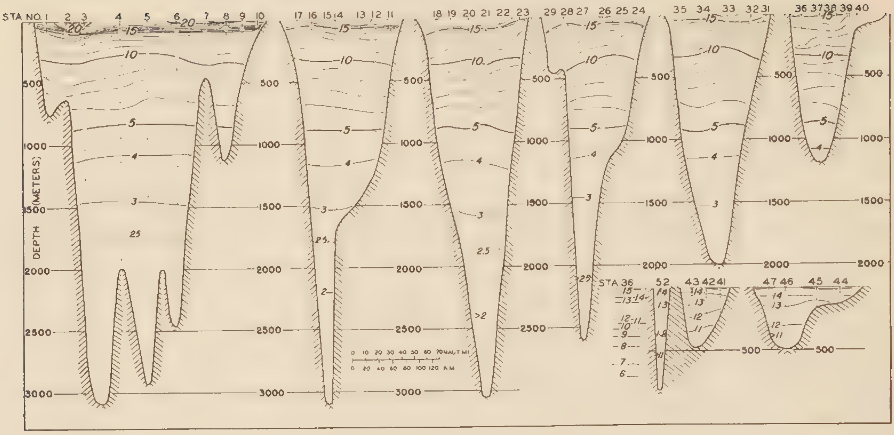

Fig. 2. Temperature profiles across the Gulf of California, *E. W. Scripps* cruise, February 13–March 19, 1939.

across Angel de la Guardia Island toward the peninsula, and one section across the middle part of the inner portion of the Gulf.

It is seen that in the outer portion of the Gulf, south of Tiburon Island, the surface temperature decreased toward the north. Between Cape San Lucas and Mazatlán the surface temperature was above 21° at two stations, whereas off Tiburon Island the surface temperature was barely above 15°. Near the surface, evidence of upwelling is found on the eastern ends of Sections 3 and 6. Below a depth of 200 or 300 meters the temperature was very uniform and decreased regularly towards the bottom, where a temperature of less than 2° was found below 2600 meters in the outer sections. The somewhat higher temperatures in the deeper portions of Sections 3 and 4 indicate that transverse sills are present.

In the inner portion of the Gulf the distribution of temperature was entirely different. Even in the deepest parts a temperature of about 11° was found. This indicates that the inner portion is separated from the outer by a sill, which probably runs about south-southeast from Tiburon Island and

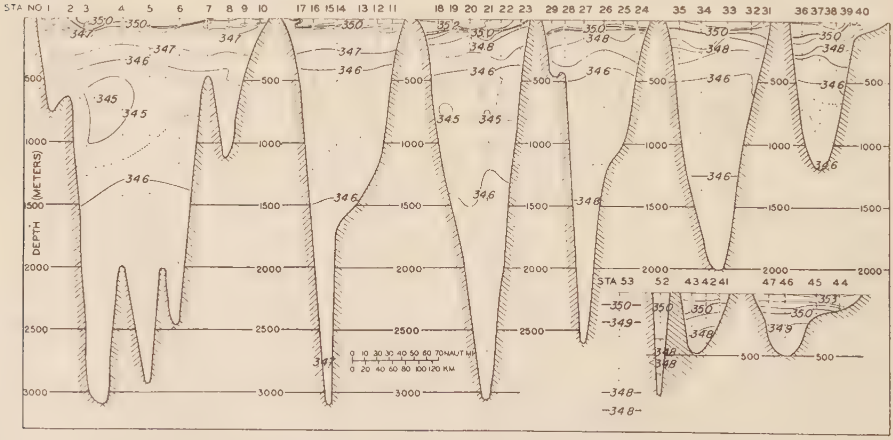

Fig. 3. Salinity profiles across the Gulf of California, *E. W. Scripps* cruise, February 13–March 19, 1939.

has a maximum depth of 200 to 250 meters. Thus, basin conditions exist in the inner portion.

The distribution of salinity (fig. 3) showed similar features. Everywhere, the highest salinities were found near the surface, but the maximum values increased somewhat from the opening toward the head of the Gulf. Near the surface the salinity curves also indicate upwelling at the eastern ends of Sections 3 and 6. In the outer portion a layer of salinity minimum is present at depths between 500 and 1100 meters. The lowest values, slightly below 34.5‰, are near the mouth of the Gulf. Farther north they are between 34.5‰ and 34.55‰. The salinity distribution also indicates that basin conditions exist in the inner portion. From the course of the isohalines in the two northern sections of the outer portion it appears, however, that an exchange of water takes place at a depth of 150 to 200 meters. The highest surface salinity, 35.5‰, was found in the central part of the inner portion of the Gulf, but about forty miles from the mouth of the Colorado River the salinity was nearly as high, being 35.12‰. Thus, a direct effect of the fresh water of the Colorado River is not evident, probably because of the excessive evaporation in winter.

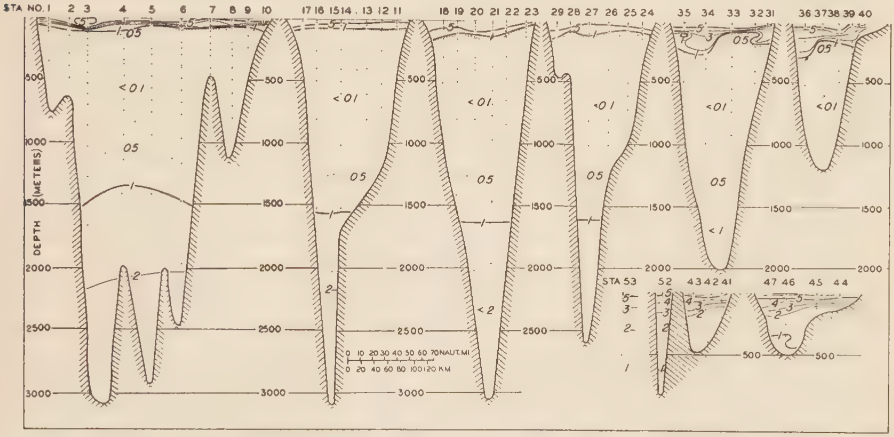

Fig. 4. Oxygen profiles across the Gulf of California, *E. W. Scripps* cruise, February 13–March 19, 1939.

The temperature and salinity combined clearly show that the deep water in the outer portion of the Gulf is of the type encountered over a great part of the equatorial regions in the Pacific Ocean. Water of similar character has previously been found off Central America and at least as far west as to longitude 180°. This water is characterized by a salinity minimum of approximately 34.5‰ at a temperature of about 5° and by very small amounts of oxygen at intermediate depths.

The lack of oxygen at intermediate depths is also very characteristic of the waters of the Gulf. The oxygen sections (fig. 4) show that the oxygen content is higher than 1 ml/L in the upper 100 m. only, and that at a depth of less than 150 m. has decreased to 0.5 ml/L. The oxygen distribution also indicates upwelling at the eastern ends of Sections 3 and 6 and shows that an exchange of water takes place between the inner portion and the outer portion of the Gulf. Between about 150 meters and 900 meters the oxygen content has been entered as being less than 0.1 ml/L and was probably less than 0.05 ml/L, because the amount was too small to be accurately determined. The deep water again contains more oxygen, up to 2.6 ml/L, as does the deep water of the central Pacific Ocean. In the inner portion of the Gulf the oxygen content is higher than in the outer, values below 1 ml/L being found only near the bottom in some localities. The higher oxygen content indicates that the deep water in the inner portion is formed by a mixture of water flowing over the sill and water which in winter may sink to great depths because of excessive cooling and evaporation. This process of vertical mixing in the inner portion and the process of upwelling account for the great fertility of the waters of the Gulf.

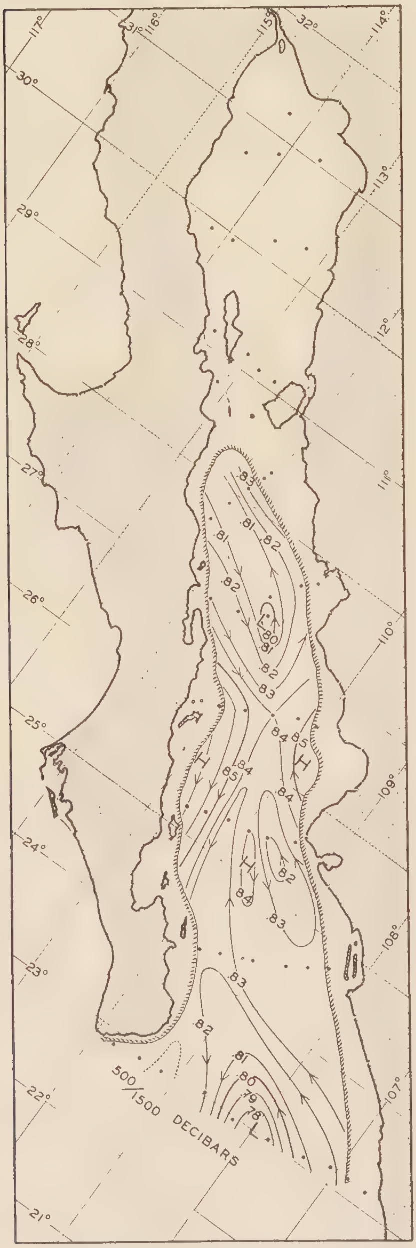

Fig. 5. Dynamic topography of the 500-decibar surface relative to the 1500-decibar surface. Gulf of California, *E. W. Scripps* cruise, February 13–March 19, 1939.

A study of the currents in the outer portions of the Gulf by means of dynamic computations led at first to very discouraging results. The topography of the 500-decibar relative to the 1500-decibar surface (see fig. 5) does not indicate any regular exchange of water between the Gulf and the adjacent part of the Pacific, but shows a sequence of separate highs and lows. A further examination of the data brought out the fact that the character of the water below 200 m. is the same at all stations in the outer portion of the Gulf, but at some stations the temperature, salinity, and σ_t curves appeared to be displaced upward, while at other stations they appeared to be displaced downward. The displacements are clearly seen in a longitudinal section (fig. 6) based on data from stations along the center line of the Gulf. To the left in the figure is shown a small map of the Gulf on which are indicated the stations in the Gulf and the *Bushnell* Station 305, which have been used for constructing the section. On the central part of the figure are shown the wave-shaped σ_t curves. It should be observed that the vertical scale is highly exaggerated relative to the horizontal, the ratio between vertical and horizontal scales being equal to 1/800. To the right in the figure are shown the profiles of a series of isobaric surfaces relative to the 1500-decibar surface.

The wavy character of the curves suggests the possibility that they may be associated with a standing internal wave. The observations are not simultaneous, but at the top right-hand corner of the figure are shown the number of days elapsed between occupation of Station 5, the central station of the southern section, and the other stations used for constructing the profile. It is evident that if the observations indicate a standing wave, the wave period must be such that when traveling up the Gulf the vessel remained nearly in phase with the wave. This gives immediately an indication of the possible period length. Station 14 appears to have been occupied near a node of the wave, and in this case the time difference is of no importance. Station 21 appears to have been occupied shortly before the wave reached its highest value, and the wave period may therefore have been greater than 12.6/2, which means greater than 6.3 days. Station 27 was occupied after the wave had reached its crest and the wave period may therefore have been less than 15.3/2, which means less than 7.65 days. Station 30 appears to have been reached approximately at the time when the wave at the surface reached its lowest position and the wave period may therefore be approximately 19.3/3, which means approximately 6.4 days. Finally, Station 38 must have been reached nearly at the time of greatest elevation. Therefore the period may be approximately 25.3/4, which means about 6.3 days. Thus, the period may lie between 6.3 and 7.65 days and probably lies closer to the former value. A period length of about 6.6 days or 5.7×10^5 seconds appears to fit the data very well, but no multiple of this period length will do so. No use has been made of the time interval between Stations 5 and 305 because the latter also appears to have been occupied near a node. Thus, the data can be interpreted as showing the existence of a standing internal wave with a node near the broad opening of the Gulf and with three more nodes located in the Gulf. In the outer portion of the Gulf the wave length appears to be of the order of magnitude of 1000 km., but it decreases greatly toward the inner end. This decrease is undoubtedly associated with the decrease of depth. A wave length of about 1000 km. and a period of about 5.7×10^5 sec. gives a velocity of progress in the outer portion of 175 cm/sec. Furthermore, it is evident from the σ_t curves that one has mainly to deal with an internal wave of the first order having a maximum amplitude at an intermediate depth and zero amplitude at the surface and at the bottom. From the σ_t curves one finds that the maximum amplitude lies between 500 and 600 m. and is of the order of magnitude of nearly 100 meters.

It is possible to check these conclusions by a computation of the possible internal waves, using Fjeldstad's method (1933) of numerical integration. One difficulty is, however, encountered because the bottom of the Gulf is so irregular that what may be called the "effective" depth cannot readily be determined. From the observations at the deepest stations it appears that continuous communication between the various depressions is present only above 2000 meters. In computing the possible internal waves it has therefore been assumed that the depth to the bottom can be taken as 2000 meters, but it can be added that results would not be very much altered by assuming a greater or somewhat lesser depth. On this assumption the computation of the possible internal waves by Fjeldstad's method leads to the result that between Cape San Lucas and Mazatlán the internal wave of first order has a velocity of progress of 175 cm/sec. and that the maximum amplitudes occur at a depth of 775 meters. The agreement between these values and those which were derived directly from the observations is so good that the existence of a standing internal wave during the time of the cruise cannot be doubted. A study is in progress of the modifications of the wave length due to the decreasing depth. It is hoped that it will be possible to find theoretically the location of the nodes near the northern end of the Gulf.

It is evident that this internal wave completely obscures any distribution of density which may be related to the circulation of the deep water. Such circulation probably is present and consists of a slow exchange of water between the Gulf and the adjacent part of the Pacific, but the nature of this exchange cannot be found on the basis of our data.

It should, however, be observed that the upper isobaric surfaces slope upward from the inner part of the Gulf toward the opening of the Gulf. This general slope is indicated on the right-hand graph in figure 6, from which it is seen that the upward slope of the free surface is much greater than that of the 100-decibar surface. It thus appears that a certain amount of piling up of surface waters takes place which is probably a result of the prevailing northerly and northwesterly winds during February and March. When cruising up the Gulf, the *E. W. Scripps* encountered several strong winds blowing intermittently out of the Gulf. The pilot charts show that winds from the north and northwest prevail in the spring and that the average velocity of these winds is about 3.5 m/sec. When discussing data from the Caribbean Sea (1939) I have been able to show that the average wind velocity can be computed from oceanographic data if one knows the variation of the distribution of density in the direction of the wind. The application of this method to the data from the Gulf is made difficult by the presence of the internal wave. The selection of stations to be compared can be made in various ways, and different combinations lead to computed wind velocities between 3.5 and 7.5 m/sec., the former value being the more probable. This value is in good agreement with the general average wind velocity and it can therefore safely be assumed that the piling up of the light surface waters at the entrance of the Gulf is caused by the prevailing northerly winds.

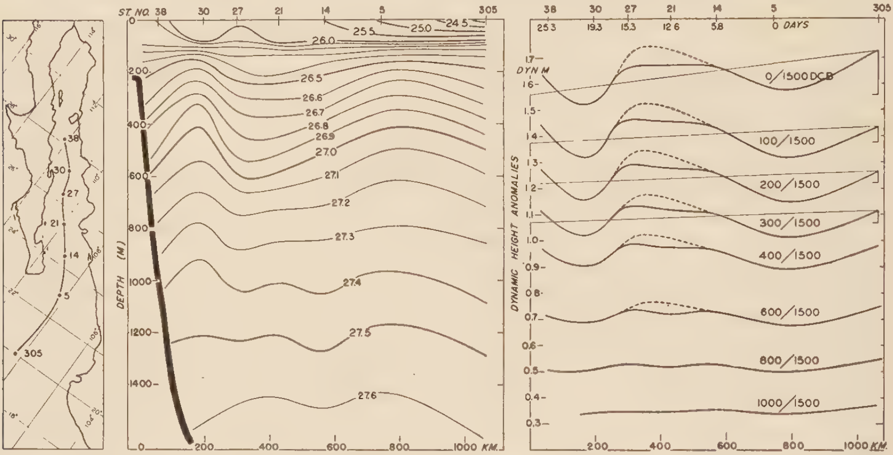

Fig. 6. Center: Longitudinal section of the Gulf of California showing distribution of σ_t according to observations at stations plotted on chart to the left. Right: Longitudinal profiles of isobaric surfaces relative to the 1500-decibar surface.

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A CONTRIBUTION TO THE OCEANOGRAPHY OF THE CENTRAL AMERICAN REGION

By Richard H. Fleming

In a symposium on the currents near the coasts of the Pacific Ocean it is of great interest to discuss the conditions in the Central American region. This area is the meetingplace of three of the great currents of the Pacific, namely, the California Current, the Peru Current, and the Equatorial Counter Current, and it is the place of origin of the Northern and Southern Equatorial Currents. The general pattern of circulation at the surface is as follows. Both the California Current and the Peru Current are deflected westward and the water of the Counter Current turns on itself to augment the flow of the Northern and Southern Equatorial Currents. The generalized chart (fig. 1) is based on the data from the Pilot Charts published by the United States Hydrographic Office. On these, the average currents have been computed for each quarter of the year and for each one-degree quadrangle for which there are sufficient data. Where the current flows in one direction for at least three of the four quarters solid arrows are used. Where the currents are less steady, broken arrows are used, and regions of great variability are indicated by crosses.

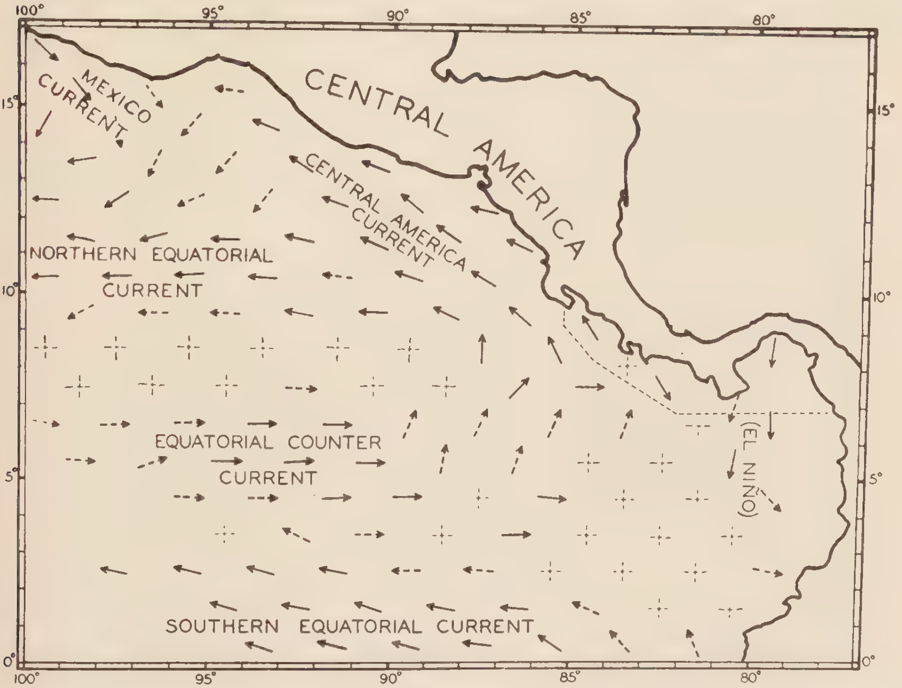

Fig. 1. Generalized pattern of surface flow in the Central American region. Crosses indicate areas of variable currents.

The southward flow along the coast of North America barely enters the chart, where it is indicated as the Mexico Current. Most of the Northern Equatorial Current in the area shown is supplied by the Counter Current, which is deflected north and west along the coast as the Central America

Current. The Peru Current is the source of the water flowing westward in the Southern Equatorial Current, and it should be noted that this extends across the equator into the Northern Hemisphere. The Equatorial Counter Current is bordered by zones of weak or indefinite flow, and the region to the south and west of the Gulf of Panama shows no permanent pattern of currents. The reason for the existence of areas of no permanent flow in the generalized chart is not that currents are lacking in the areas, but rather that they fluctuate so widely because of the annual cycle in the location of the Equatorial Currents. During the northern summer the system is displaced northward and the Southern Equatorial Current then flows in toward the Gulf of Panama and northward. During the northern winter, when the wind systems are displaced somewhat southward, the Counter Current is in large part broken down and most of the water is then carried away by the Southern Equatorial Current. The northerly wind, which at this season of the year blows across the land from the Atlantic, brings about marked upwelling in the Gulf of Panama and along the coast of Central America. The light, warm water normally present is driven southward and in exceptional years it is found along the coast of Peru where it is known as "El Niño."

In figure 2 the surface currents are shown by means of stream lines for each of the four quarters of the year. These have been constructed from the average current for each one-degree square shown on the Pilot Charts. The extremely complicated nature of the flow during the winter is reflected in the charts for both the winter and spring quarters. Actually the marked disturbance at this season of the year is restricted to January, February, and

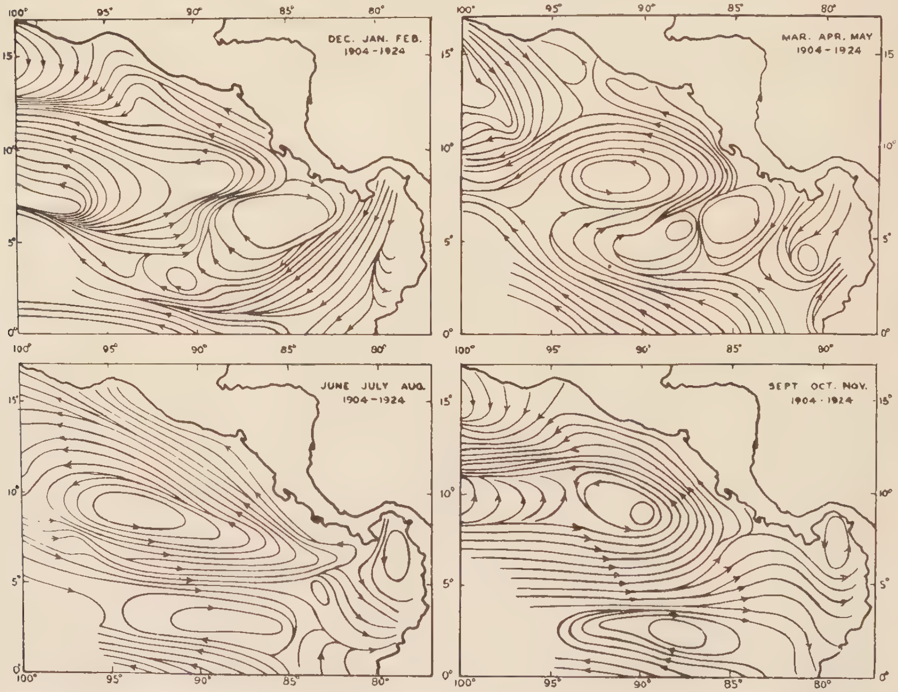

Fig. 2. Seasonal variation in the surface currents in the Central American region. Stream lines for each quarter of the year are based on the average currents for one-degree quadrangles given on the U. S. Hydrographic Office Pilot Charts.

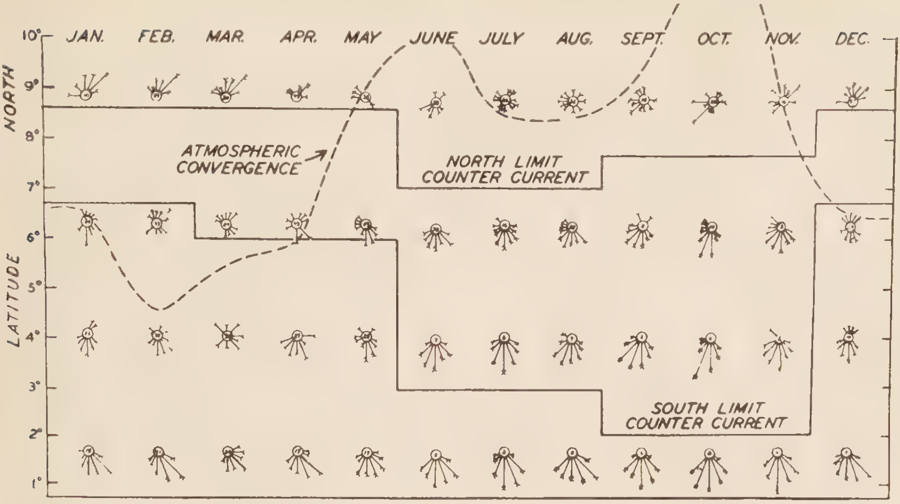

Fig. 3. Seasonal shifts in the winds and surface currents in the Central American region between longitudes of 85° W and 87.5° W. Dashed line represents position of the convergence between the Trade Wind systems. Wind roses taken from U. S. Hydrographic Office Pilot Charts.

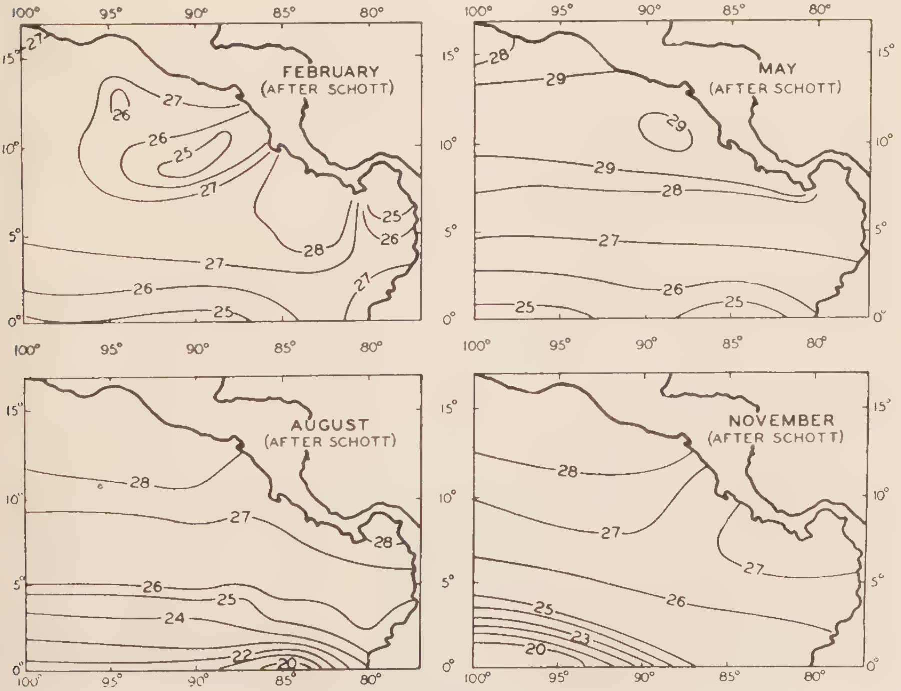
FEBRUARY
(AFTER SCHOTT)
MAY
(AFTER SCHOTT)
AUGUST
(AFTER SCHOTT)
NOVEMBER
(AFTER SCHOTT)
100°
95°
90°
85°
80°
15°
10°
5°
0°

Fig. 4. Seasonal changes in the surface temperatures in the Central American region. (After Schott.)

March, as will be shown later. It is unfortunate that the quarters selected by the Hydrographic Office do not correspond to this interval. During the summer and fall quarters the pattern of flow is much more clearly defined.

The relationship of the current system to the winds is shown in figure 3. The wind roses were taken from the Pilot Charts for each month and for the zone between 85° and 87°5 W. The broken line represents the position of the atmospheric convergence, taken from Werenskiold (1922). In the winter months the convergence has its most southerly position; and its most northerly occurs in the autumn. The northern and southern limits of the Equatorial Counter Current are entered for each quarter. It may be seen that the northerly winds extend nearer the equator during the winter and that at this time the Counter Current is much reduced. During the rest of the year, when the winds are from the south and west, part at least of the easterly flow may be due to these winds. Although this figure applies only to the band between 85° and 87°5 W, a similar sequence of events would be found at other longitudes.

Corresponding to the shifts in the current system there are conspicuous changes in the distribution of surface temperatures, as shown in figure 4, which has been prepared from the charts given by Schott (1935). In February, upwelling along the Central American coast reduces the temperatures and it will be shown later that the temperatures in the Gulf of Panama are reduced much below 25° at this time of the year. The relatively cold water of the Peru Current and of the equatorial divergence show up conspicuously in the charts for August and November, when warm water is carried in by the Counter Current.

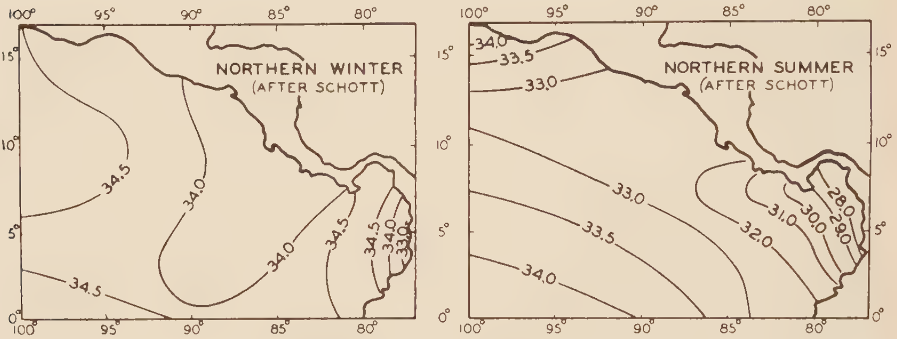

Fig. 5. Surface salinities during the northern winter and northern summer. (After Schott.)

The distribution of surface salinity during the northern winter and summer are shown in figure 5, prepared from charts given by Schott (1934). During the northern summer there is a band of extremely low salinities extending westward from the Gulf of Panama. These low salinities are maintained by the excessive rainfall in the equatorial calm belt, particularly near the coast of Central America where there is very heavy precipitation during this season of the year. During the northern winter the salinities at the surface are much higher, for the following reasons: first, the rainfall is much less; and second, the low-salinity water has been driven south and west away from the coast by the northerly winds.

In figure 6 are shown various observations from the Gulf of Panama. The change in the percentage of winds from the northern quadrant corresponds to the variations in rainfall mentioned above. The effects of the dry, northerly winds upon the conditions in the Gulf of Panama are shown by the curves representing the average monthly values of surface temperatures and sea

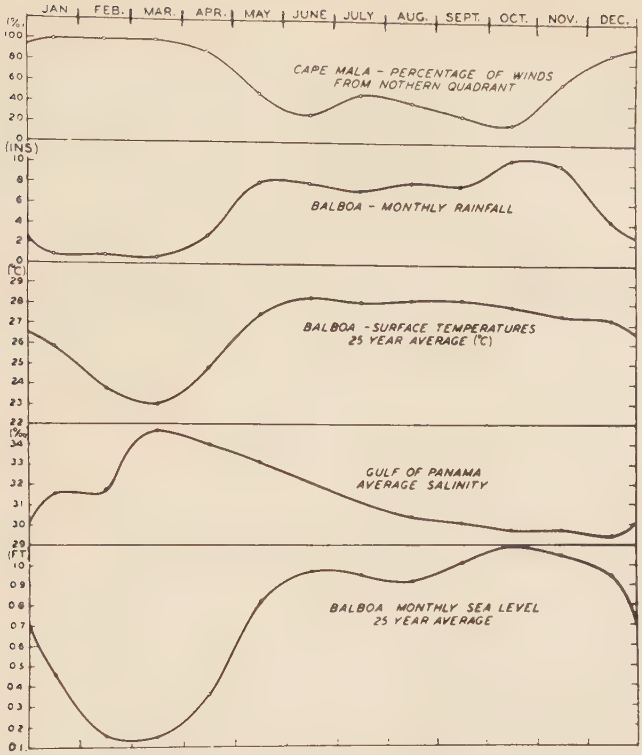

Fig. 6. Monthly values of winds, precipitation, surface water temperature, salinity, and sea level in the Gulf of Panama.

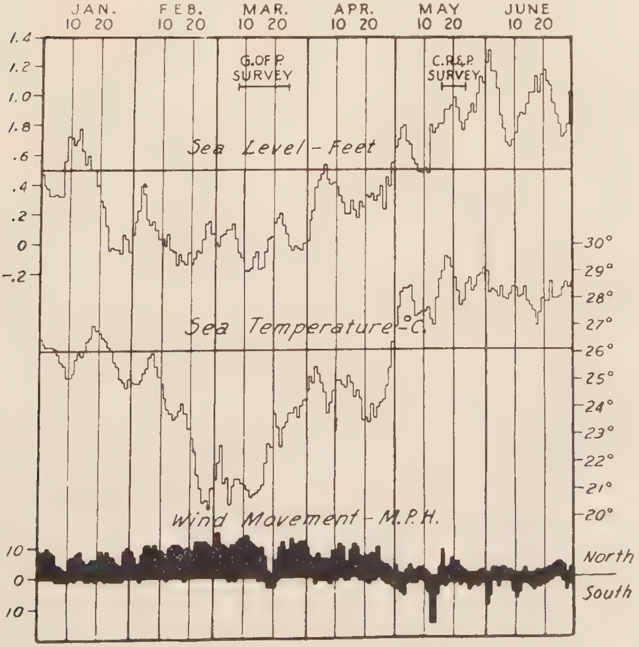

Fig. 7. Daily values of the winds, surface water temperature, and sea level at Balboa, C. Z., for the first six months of 1933.

level at Balboa, Canal Zone. Comparable data are not available for salinity, but the curve for this variable represents the monthly average of a large number of observations collected in the Gulf of Panama. With the displacement of the surface water there is a drop in temperature and a rise in salinity which is reflected in the lowered sea level, which at this season is approximately one foot lower than during the summer and autumn months. If surface temperatures are taken for individual months or weeks, they are found to be much lower during this period. Temperatures as low as 16° and salinities of nearly 35.0‰ were obtained in the Gulf of Panama during March (Fleming, 1934 and 1935). That there is a very close relationship between the winds and the surface temperatures and sea level is shown in figure 7, which is based on averages for individual days in 1933.[1]

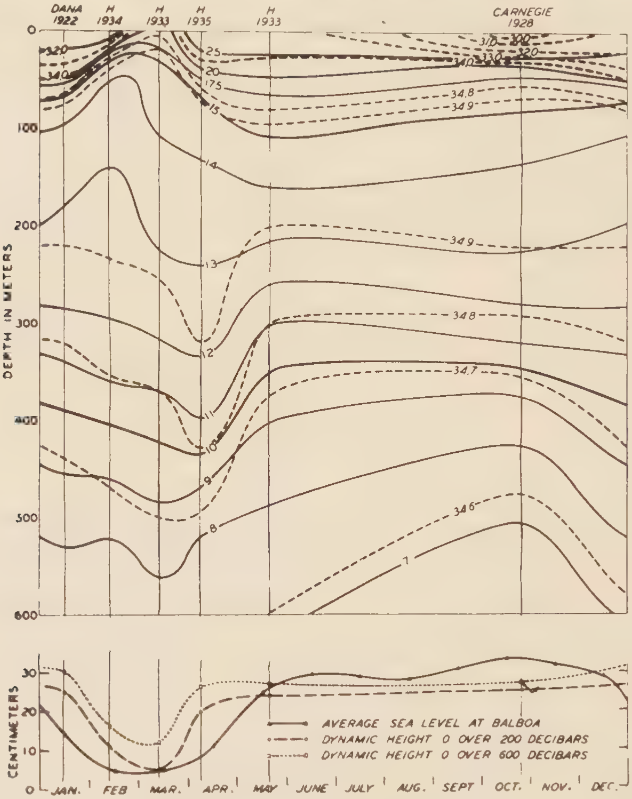

Fig. 8. Seasonal changes in the vertical distribution of temperature and salinity in the Gulf of Panama. At the bottom of the diagram are shown the curves representing the observed changes in sea level at Balboa and the dynamic height anomalies 0 over 200 decibars and 0 over 600 decibars, corresponding to the temperature and salinity distribution shown above.

The effect of the displacement of surface water on the conditions at subsurface layers is shown in figure 8, which is based on data obtained in the Gulf of Panama at different times of the year. However, it should be noted that these observations were not obtained in any single year. It can be seen from this figure that about 75 meters of water are driven out during the winter months and replaced by cold, highly saline water. In the lower part of the diagram is shown the average sea level and the dynamic heights corresponding to the temperature and salinity distribution shown in the upper part of the diagram.

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[1] The data on surface temperatures and sea level at Balboa and winds (fig. 7) were supplied by L. T. Chapel of the Hydrographic Office of the Panama Canal Zone.

Examination of the temperature-salinity characteristics of the subsurface water have shown them to be extremely uniform in the Central American region. At temperatures of less than 15°, almost all points fall between the limiting curves shown in figure 9. The heavy line represents the average temperature-salinity curve, based on observations at forty-one stations off the coast of Costa Rica and Panama (Fleming, 1934). From this it may be seen that the upwelling in the Gulf of Panama during the winter months removes the warm, low-salinity water and that conditions at the surface approach the point marked *S.Ö.S.*, which has a temperature of 14° and a salinity of 35.0 ‰. During the upwelling period the quantity of this type of water increases. It is probable that this water has its origin to the south of the equator, as water of this character is found at the surface off the coast of Peru (Thomsen, 1935).

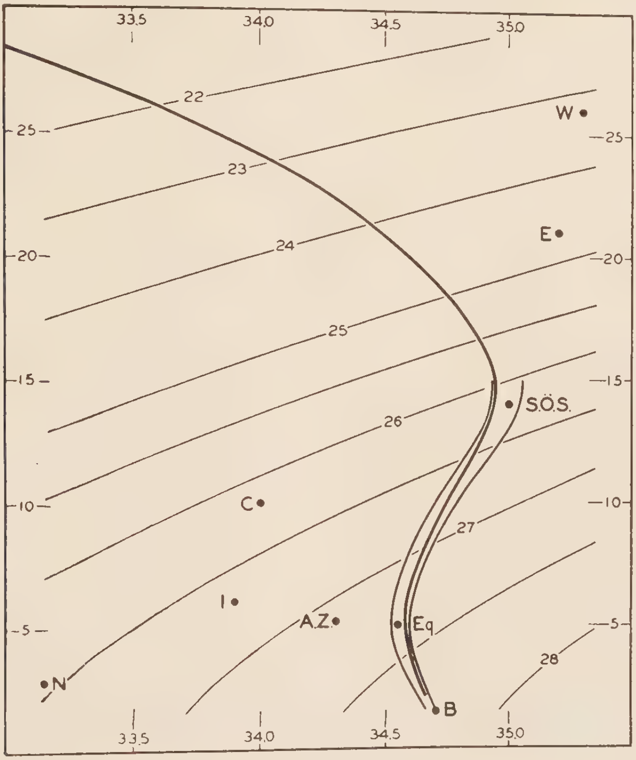

Fig. 9. Limiting curves defining the temperature-salinity relationship for the Central American region. Heavy curve is the average T-S curve for 41 stations occupied off the coast of Costa Rica and Panama. Fine lines represent ${}_t$ curves.

During the period of upwelling, tremendous quantities of plant nutrients are brought to the surface within the Gulf of Panama and as a result there is a large production of phytoplankton (Allen, 1939). Further evidence of the productiveness of this region is supplied by the observations of the *Dana* (Jespersen, 1935). Extremely large quantities of macroplankton were obtained in this area at intermediate depths.

One of the characteristics of the subsurface levels in the Central American region is the very low dissolved oxygen content of the water, as is shown in figure 10.

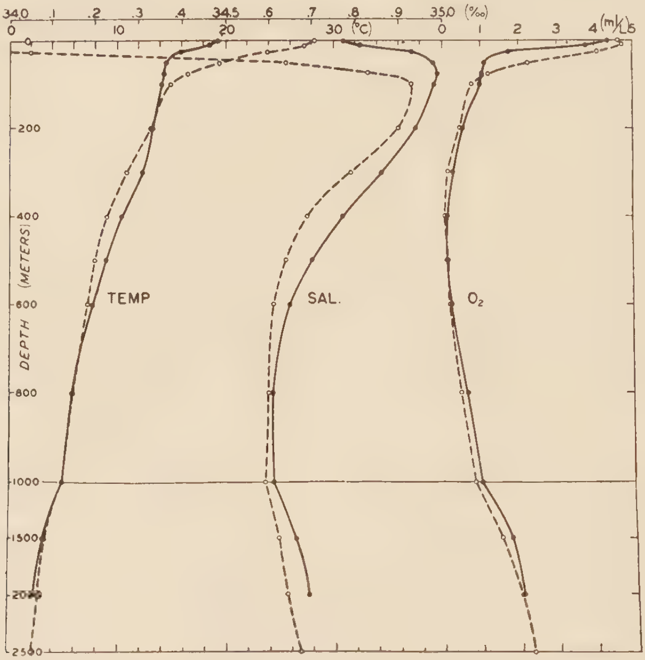

Fig. 10. Vertical distribution of temperature salinity and oxygen. Solid lines represent the average of 86 stations occupied in the Gulf of Panama in March, 1933, and dashed lines the average of 41 stations occupied off the coast of Costa Rica and Panama in May, 1933.

The Central American region is one of complex surface currents, and in addition it is extremely interesting because of the tremendous range in conditions which are encountered during the course of the year and the fact that the environment is favorable for the development of organisms in quantities that are usually considered to be restricted to the higher latitudes.

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STUDIES OF THE PERU COASTAL CURRENT WITH REFERENCE TO THE EXTRAORDINARY SUMMER OF 1939

By E. H. SCHWEIGGER

IN 1929 the Peruvian Government decided to inaugurate scientific investigations on the coastal current of Peru, not only to make a contribution to oceanographic science, but also for the purpose of augmenting Peruvian fisheries, to study the hydrographic basis for knowledge of the life and migrations of fish.

The ship *Tres Hermanos* of the Compañía Administradora del Guano was designated for these investigations, but after the end of the 1929–30 guano collecting season there was no opportunity to continue the studies, as the boat remained at its anchorage at Callao. The oceanographic work was therefore limited to the trips which the ship incidentally made between the islands and the ports in carrying out its regular service, the result being that nearly all the studies were restricted to locations near the coast and at the ports themselves.

Internal difficulties put an end to these investigations in October, 1930. In its *Bulletin* of January, 1931, the Compañía Administradora del Guano published a summary of the observations and investigations carried out to that date.

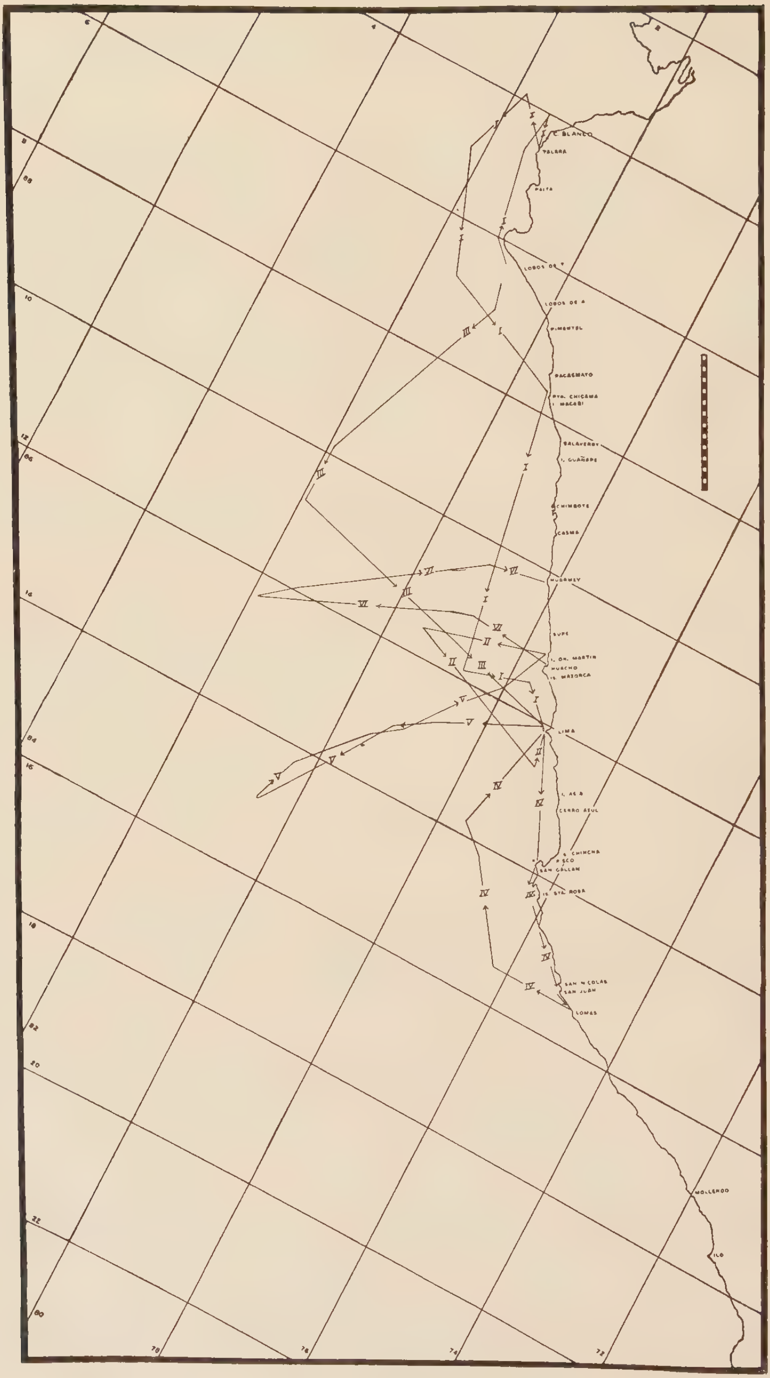
During this same period the German scientist G. Schott traveled along the western coast of South America studying the Peruvian current. A result of this visit was the well-known publication on this current, "Der Peru-Strom und seine nordlichen Nachbargebiete in normaler und anormaler Ausbildung," Ann. d. Hydrogr. *u. marit. Meteorologie,* 1931, a publication based also on the meteorological and oceanic observations supplied by all the German boats which travel along this coast and which are obliged to supply information to the *Deutsche Seewarte,* Hamburg. Thus there was assembled in the *Seewarte* an abundance of material pertaining to every month of the year and covering a space of many consecutive years, also permitting the interpretation of the extraordinary phenomena produced by the El Niño Current in the summers of 1891 and 1925.

During June, July, and August, 1931, the British scientist E. R. Gunther made investigations off the coast of Chile and Peru on board the *William Scoresby*—studies amplified by others carried out in sections at right angles to the coast, at some points to 200 miles at sea ("A Report on Oceanographic Investigations in the Peru Coastal Current," *Discovery Rept.,* Vol. XIII, 1936).

The publications of Schott and Gunther were the first that attempted to fix the zones of the upwelling of the colder waters from subsurface depths, to which are attributed the extraordinary conditions of a coast with a climate corresponding to higher latitudes.

During the first weeks of 1935 the yacht *Velero III,* owned and commanded by Captain Allan G. Hancock, carried out new investigations in relation to the Peru Coastal Current and obtained new knowledge concerning the distribution of temperatures in the Peruvian sea. I regret being unable to give the title of any publication covering this investigation.

In 1938 the Compañía Administradora del Guano, with the approval of the Peruvian Government, started new oceanographic investigations on the Peruvian coast and out at sea. This time, also, the investigations were directed toward establishing an internal connection between maritime conditions and the possibilities for a larger-scale fishing industry on the high seas than exists today. The studies were begun (apart from occasional observations on voyages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C. BLANCO
TALARA
PAITA
LOBOS DE T.
LOBOS DE A.
PIMENTEL
PACASMAYO
PTO. CHICAMA
I. MACABI
SALAVERRY
I. GUAÑAPE
CHIMBOTE
CASMA
HUARMEY
SUPE
I. DN. MARTIN
HUACHO
IS. MAZORCA
LIMA
I. AS A
CERRO AZUL
I. CHINCHA
PISCO
SAN GALLAN
IS. STA. ROSA
SAN NICOLAS
SAN JUAN
LOMAS
MOLLENDO
ILO
I
II
III
IV
V
VI

MAP 1

near the coast) in November, 1938. Owing, however, to temporary lack of necessary scientific equipment, they had to be limited to the surface of the water. The program for these studies included four voyages during the year, following different courses, to and from the shore and going out to a depth of 2000 meters. Before the arrival of the scientific equipment the voyages were carried out for the purpose of finding appropriate zones for future studies.

The publication of Gunther describes conditions which are of great interest so far as the fisheries are concerned when it determines the presence of a tongue of warm waters off the Peruvian coast which extends nearly to Callao, and farther south another tongue almost entering Arica. The northern tongue, reaching its maximum extension more or less off Salaverry, offered a remarkable opportunity for these regular investigation trips. But since the Schott publication makes no reference whatsoever to the existence of such a tongue of warmer waters, the question arises whether it is normal and is present every year and at all seasons, or whether it originated from the special conditions of 1931.

Very soon, and as a result of an unforeseen circumstance, an opportunity offered for the investigation of this phenomenon. The Servicio Meteorológico Nacional del Perú received advice concerning an abnormal rise in the temperature of the waters off Cabo Blanco toward the end of October, 1938. As the winter of 1938 had extremely low temperatures, not only on the coast itself, but also on the guano islands, so strong a rise in temperature in the north seemed to indicate another abnormal happening because such temperatures as were observed at the end of October are normal for the end of November or the beginning of December.

According to the regular reports received at Lima, the condition off Cabo Blanco soon afterward returned to normal, but on November 6 another extraordinary increase in temperature was announced. Therefore the Campañía Administradora del Guano made available for investigation its ship *Chincha,* which sailed from Callao November 19, carrying among others, the Chief of the National Meteorological Service, Mr. Guillermo A. Wagner. This voyage had two purposes: first, to establish what were the oceanographic conditions at this time in the north; and second, to find out if it were possible to cross the region where, according to the publication of Gunther, the tongue of warm waters ought to be encountered.

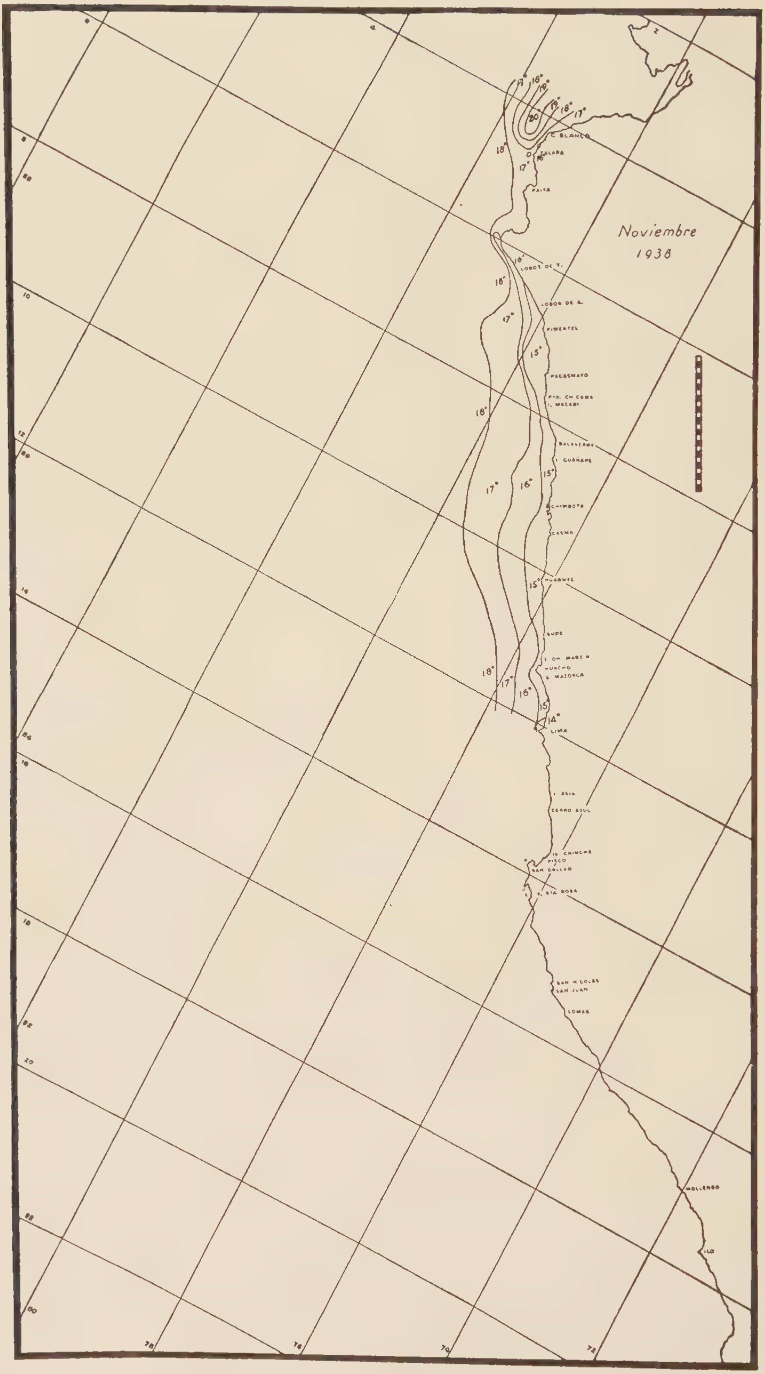
After this first voyage five more were carried out, as follows: first voyage, from November 18 to 26, 1938, by steamer *Chincha* (I); second voyage, from January 17 to 27, 1939, by steamer *Chincha* (II); third voyage, from February 11 to 18, 1939, by steamer *Chincha* (III); fourth voyage, from March 8 to 14, 1939, by steamer *Chincha* (IV); fifth voyage, from April 3 to 7, 1939, by small boat *Tellus* (V); sixth voyage, from May 13 to 17, 1939, by small boat *Tellus* (VI). (See map 1, on which these trips are shown and designated by Roman numerals.)

With the exception of the first voyage, all the trips had as their purpose the crossing (if possible) of the Humboldt Current, or rather adopting the nomenclature of Gunther, the Peru Coastal Current.

As we have mentioned before, owing to lack of special equipment, all the investigations had to be limited to the surface; but it was possible to make annotations on the climate in general of the zones visited.

It may be stated in advance that on all the voyages since January, 1939, it has been possible to cross the Peru Coastal Current.

On the first voyage (map 2) the boat took course Callao–Isla Lobos de Tierra, at a distance of approximately 15 miles from the coast. The temperatures recorded, with a few exceptions, did not go above 15°9 until the position


Noviembre
1938
20°
19°
18°
17°
16°
15°
14°
C. BLANCO
TALARA
PAITA
LOBOS DE T.
LOBOS DE A.
PIMENTEL
PACASMAYO
PTO. CHICAMA
I. MACABI
SALAVERRY
I. GUAÑAPE
CHIMBOTE
CASMA
HUARMEY
SUPE
I. DN MARTIN
HUACHO
I. MAZORCA
LIMA
I. ASIA
CERRO AZUL
IS. CHINCHA
PISCO
SAN GALLAN
I. STA ROSA
SAN NICOLAS
SAN JUAN
LOMAS
MOLLENDO
ILO

MAP 2

of 7° 20′ S and 80° 15′ W, and only a bit further north—especially near the Isla Lobos de Tierra—was observed a rise in the temperature to a little above 18°.

Such low temperatures we must consider as abnormal. Schott's maps for August and September show Puerto Chicana as the most northern point for temperatures of 17°, that is to say, more or less latitude 7° 45′ S. According to our knowledge of the annual cycle of marine temperatures, obtained from regular observations on the guano islands and averaged from the year 1934 on five-day intervals, the period of the lowest temperatures is the second half of September, or, at the latest, the first part of October. From the last ten days of October on, an increase of temperature is noted every year.

This undoubtedly occurred also in the winter of 1938, but the fact that the temperatures on the coast after the first half of November had not yet reached the normal for September indicates that they had gone much lower than in normal years, an impression also confirmed by the averages of the temperature observations carried out on the guano islands.

To the north of the Isla Lobos de Tierra, the surface temperature decreased to 16°7 off Punta Aguja (6° S), but some 8 miles more to the north it went up to 17°3 and stayed at that point until Punta Pariñas (4° 30′ S), where once more it decreased to 16°5. Following its course to the north, the ship soon entered temperatures of 19°, which were maintained until latitude 4° S, where the ship turned round to go back to Talara. Near Talara, almost at the very entrance to the bay of this port, a temperature as low as 15°8 was recorded.

This temperature, and the low ones off Punta Aguja and off Punta Pariñas, seem to indicate some connection with the cold current branching off sharply to the west at these two points.

In the afternoon the boat sailed from Talara to investigate the zone to the northwest of the port and to find out if there were any indication of the appearance of warmer waters emanating from the southern part of the Gulf of Guayaquil.

At the anchorage of Talara the temperature during the day—that is, from 9:30 to 16:20—was 16°2 and 16°3, respectively. But leaving Talara there was a notable change in temperature, which can be appreciated from the following:

Time	Miles traversed	Temperature at the surface
16:20	Anchorage at Talara	16°3
17:00	1.2	17°9
17:30	8.8	19°3
18:00	10.5	19°8
18:30	15.0	20°5
19:00	20.0	20°8
19:30	23.8	20°8
20:30	32.0	20°5
21:00	36.2	19°5
21:30	40.5	19°1
22:00	44.5	18°0
22:15	47.0	17°2
22:30	49.5	17°3

After reaching the temperature of 17°3, the boat turned to the south at the position 3° 52′ S, 81° 50′ W.

These observations and those taken before dawn of the same day off Cabo Blanco allow us to construct isotherms for this zone, which correspond completely to those in figures 63 and 70 of Gunther's work, the only difference being that the isotherm of 17° taken from our observations extends farther to the west and the north than those in Gunther's maps. The isotherms of Gunther
It cannot yet be decided whether the distribution of the temperatures shown
show generally higher temperatures than those observed in November, 1938.

by this trip should be considered as typical for November, or whether it is an expression of the abnormal winter of 1938 (while the isotherms of Gunther correspond to the rest of summer temperatures). Only by repeated voyages over the same course could that be cleared up.

One observation remains to be mentioned. Coming near to the belt of 20° and higher temperatures, there could be seen on the clear sky from a great distance a single dark cloud, well outlined, which extended from the northeast to the southwest and which appeared, according to special observations carried out by Mr. Wagner, to be very low. The boat passed under this cloud, which showed its maximum density in the zone of 20°8, whilst the sky remained covered for half an hour more or less and cleared up later upon our entering the waters of 19°1. During that time the wind blew from the west, and changed upon our entrance into waters of 19°1 to the north-northwest. The observations farther to the south, after the boat had been turned, showed also a larger extension of the cold waters (17°) than that found by Gunther. Not until the boat had gone 32 miles farther were waters of more than 18° again encountered. In comparison with Gunther's results it should be stated that in November, 1938, the boundary of the zone of 18° remained at least 30 miles farther to the west.

After leaving Puerto Chicama, the course led through the zone shown by Gunther in his figure 63 with temperatures up to 20°. But the whole of this region, for which Gunther noted temperatures of 20° and 19°, showed no more than 17°, and only the most southerly part (circled in 10° 50′ S, 78° 45′ W; 11° 55′ S, 78° 32′ W; and 11° 48′ S, 77° 50′ W) showed higher temperatures, above 18°, with the maximum almost at the center of that space of 18°9.

If there did exist a belt of warmer waters in this part of the sea, as in accordance with the descriptions of Gunther, it must have been more to the west.

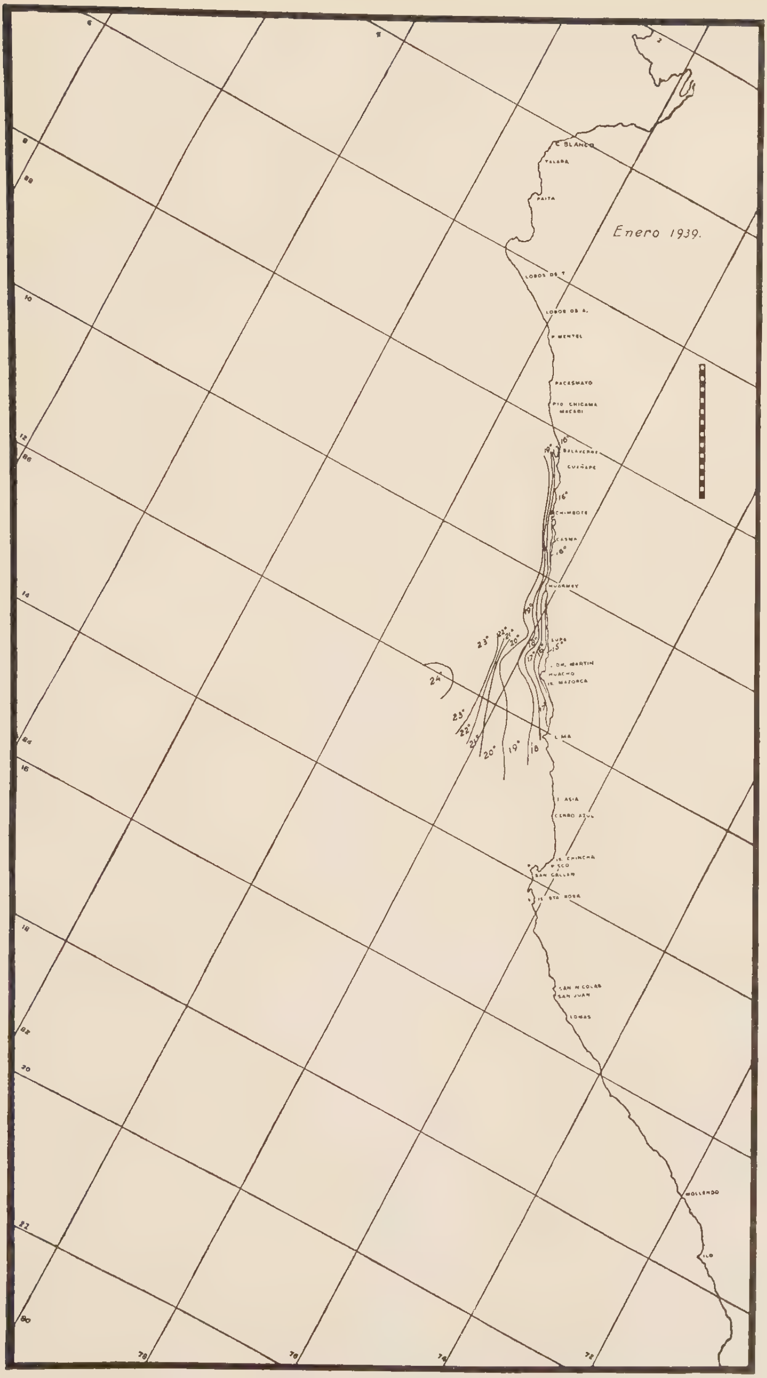
It is not yet possible to pass upon the discrepancies between these two observations, as a final decision will require systematic investigation. But it is possible that the cold winter with abnormally low temperatures at the surface of the sea forced this belt of warm waters away from the coast.

It should be added that to the north of San Lorenzo Island there was observed a temperature of 14°1, while Gunther for the same location shows a temperature of approximately 17° on his map for the period June–August.

Simultaneously with the very low temperatures of the winter of 1938 there were observed some reactions of the guano birds, which, probably for lack of food, were obliged to abandon the islands in search of anchovetas. These fish at the end of June, 1938, were found in waters of 15°5 at 35 miles' distance from the Chincha Islands and did not return during that period either to the coast or to the islands. The lack of anchovetas near the Pescadores (a little north of Callao) forced the birds to abandon their first hatch near the end of October.

Taking into consideration the low temperature of 14°1 in the water at the entrance to the Bosquerón del Callao, the withdrawal of the anchovetas from the Chincha Islands, where the temperatures were only slightly higher during the second half of June, 1938, and the reaction of the guano birds, one comes to the conclusion that this exceptionally cold winter greatly affected the ecology of all creatures dependent upon the sea. Surface temperatures in other years have almost never reached such low points for so many weeks. We merely mention this fact, since to illustrate it with figures and diagrams would go beyond the scope of this discussion.

The first voyage in November yielded two items of information. First, the distribution of the waters and their isotherms off Cabo Blanco showed the tendency already set forth by Gunther, with the difference that the cold


Enero 1939.
C. BLANCO
TALARA
PAITA
LOBOS DE T.
LOBOS DE A.
P. MENTEL
PACASMAYO
PTO. CHICAMA
MACABI
SALAVERRY
GUAÑAPE
CHIMBOTE
CASMA
HUARMEY
SUPE
I. DON MARTIN
HUACHO
IS. MAZORCA
LIMA
I. ASIA
CERRO AZUL
IS. CHINCHA
PISCO
SAN GALLAN
IS. STA ROSA
SAN NICOLAS
SAN JUAN
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MAP 3

waters extended more to the north and west so that at latitude 7° S the zone of 18° was 30 miles more or less to the west. Second, at latitude 11° S there was noted a warming of the waters to almost 19° in a zone where Gunther had noted cooling after having passed west of the 20° warm water belt. If these waters of slightly under 19° mentioned above signified the eastern limit of a belt of warm waters more to the west, the latter would be moved at least 60 miles west of the location where Gunther found them.

The opposite was demonstrated on voyages during the summer of 1939 with the encountering of warm waters more to the east than may be considered normal. In order to make a comparison we have two maps, one by Schott, which gives the isotherms for the months of February and March, and the other from the Scripps Institution of Oceanography, based on the observations made on the voyage of the *Velero III* in the first half of January, 1935, in which reference is made to the sea off the Peruvian coast.[1]

The difference between the two maps is considerable, as may be appreciated at first glance, but it must be admitted that the maximum of summer heat also at the surface of the sea is notable from after the first few days of February till the latter part of March. One may therefore consider the isotherms given for January, 1935, as forerunners to the distribution shown in the Schott map. We would then have a movement of warm waters to the east over a distance of some 240 miles; not only does this seem almost impossible, but it also contradicts the temperatures observed on the voyage carried out at the end of January, 1939 (map 3).

The temperatures for January, 1939, show a divergence not only from those of Schott's map, but also from those observed by the *Velero III*. To state it in a few words: on the coast the waters were even colder, and on the high sea the temperatures were higher, than on both maps.

The eastern limit of the 23° waters between 11° 20′ S and 12° 25′ S was found at this time to be approximately longitude 78° 20′ W, while this same limit on Schott's map for the height of summer is given, for the same latitude, as approximately 80° W. Even if we suppose that the lines on Schotts's large-scale map are not absolutely accurate for the determining of an exact position, it must still be admitted that they are drawn with as much care as possible, according to the numerous observations which the *Deutsche Seewarte* has available. If we consider that the dislocation of the isotherms on the Schott maps is very slight in comparison with that on small-scale maps, our observations show that the shifting of the warm waters of 23° temperature at the end of January, 1939, reached approximately 100 or 120 miles to the east of their normal position.

On the other hand, the map of the Scripps Institution shows a delay in the entrance of warm waters for January, 1935, or rather a dislocation to the east of about 100 miles in comparison with the isotherms of Schott. These two considerations make apparent the discrepancy between the investigations of the *Velero III* (1935) and those of the *Chincha* (1939). On this latter trip, at the end of January, was observed a small area of waters of 24° with its center about 12° S, 79° W, the average temperature at the north being 23°.7, which would mark the entrance of the warmer waters in this region from the southwest.

Only twenty-three days later, when the *Chincha* crossed the zone in question a second time, completely different temperatures were noted, with a surprisingly rapid increase (map 4). The eastern limit of the 23° waters had shifted to no more than some 15 miles to the east, but at the same time at a distance

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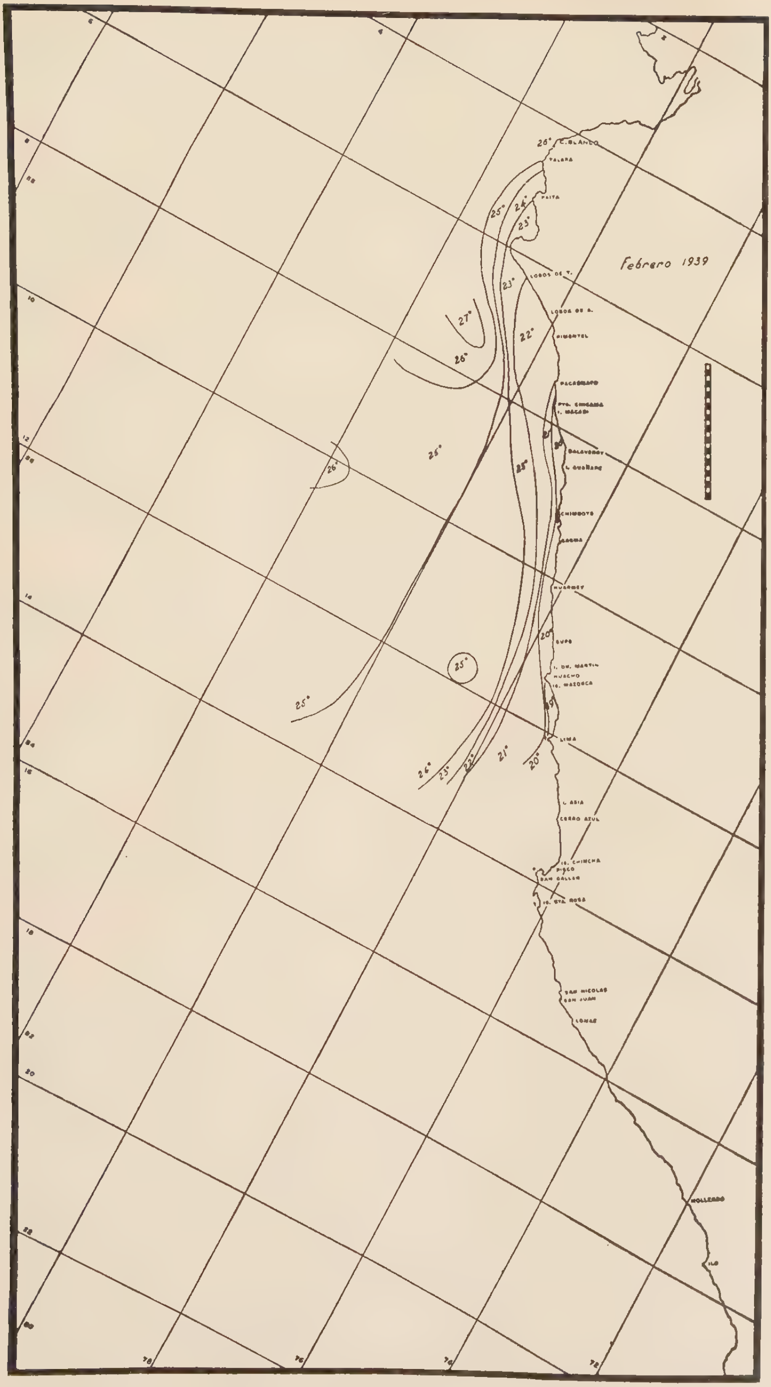
[1] This map came to our attention through the kindness of Dr. Sverdrup, to whom thanks are due also for his helpfulness on this occasion.


Febrero 1939
C. BLANCO
TALARA
PAITA
LOBOS DE T.
LOBOS DE A.
PIMENTEL
PACASMAYO
PTO. CHICAMA
I. MACABI
SALAVERRY
I. GUAÑAPE
CHIMBOTE
HUARMEY
SUPE
I. SN. MARTIN
HUACHO
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CERRO AZUL
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SAN GALLAN
IS. STA. ROSA
SAN NICOLAS
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MAP 4

of 5 or 6 miles more to the west the sea presented temperatures of 24°, and a temperature of 25° at approximately 11° 25′ S, 80° W, the most southerly point touched during the summer of 1939, that is to say, in a region for which Schott noted 23° as normal. An isolated patch of water of 25°.2 was observed at 11° 45′ S, 78° 45′ W.

The observations of this trip can only permit us to suppose that around the middle of February the isotherms of 23° and 24° from 11° S run parallel with the coast line at an average distance of 30 to 40 miles from it, and that at 12° S they are 60 miles out, but that to the north of latitude 8° S they withdraw a little from the coast, the islands of Lobos de Fuera and Lobos de Tierra lying between them.

The 25° isotherm has a different course. At latitude 11° S it appears 160 miles from the coast. But in the north we find it only 7 miles west of Lobos de Fuera Island.

Fifteen miles from this island on a southwest course the *Chincha* entered temperatures of 26°, and fifteen miles farther on it crossed a belt of 27° waters which lasted for 10 miles, when the 26° temperature was again encountered.

Altogether, this zone was crossed in an extension of 82 miles, including the 27° patch. Afterward the temperature dropped to 25°, observed during a run of 85 miles, and more to the west and south there was a notable influx of 26° water with its center at 10° 10′ S and 81° 55′ W.

At these distances, according to the maps of Schott, temperatures of 22° and 23° completely prevail, whereas in the region crossed on this voyage nothing was encountered as low as 24°, or even less than 25°.

While the distribution of temperatures to the north of Lima forms a complete though exceptional picture, the region to the south of Lima, that which was explored during the first half of March, does not give us so clear an illustration of the true conditions (map 4).

First, it should be noted that during some days in February, 1939, water temperatures of 27° were observed on the beach at Pisco, to be replaced a few days later by the normal summer temperature of 23°.[2] At the same time, to the south of San Gallán, there were cold waters with temperatures of 16°.5, which rose to 18° at the entrance to the Bay of Pisco and, by becoming mixed with warmer waters (23°), produced a temperature of 21° in the vicinity of the Ballestas Islands.

The origin of these warm waters in the Bay of Pisco is explained by two distinct factors:

1. To the south of Pisco lies the Bay of Paracas of shallow depth. For a few days in the second half of February the strong wind known as the *"Paraca"* stopped blowing and consequently these waters were heated with the full force of the sun. The warm water of 27° near Pisco, therefore, surely has its origin in the Bay of Paracas, whence (as has always been proved by observations) it flows along the coast from south to north, while a portion of a colder current enters from the north along the west side of the bay.

2. There is a north–south current flowing toward the Chincha Islands which almost always enters the Bay of Pisco along the west side. From the *Chincha,* anchored in front of North Chincha Island on March 9, 1939, this strong north–south current was observed. It is known that winds from the north blow between this island and Pisco also in winter; but these winds usually do not have much force and only constitute a light movement of air, perceptible by its direction. Furthermore, all the navigators know that they nearly always encounter a north–south current from the Island of Asia, or more to the south

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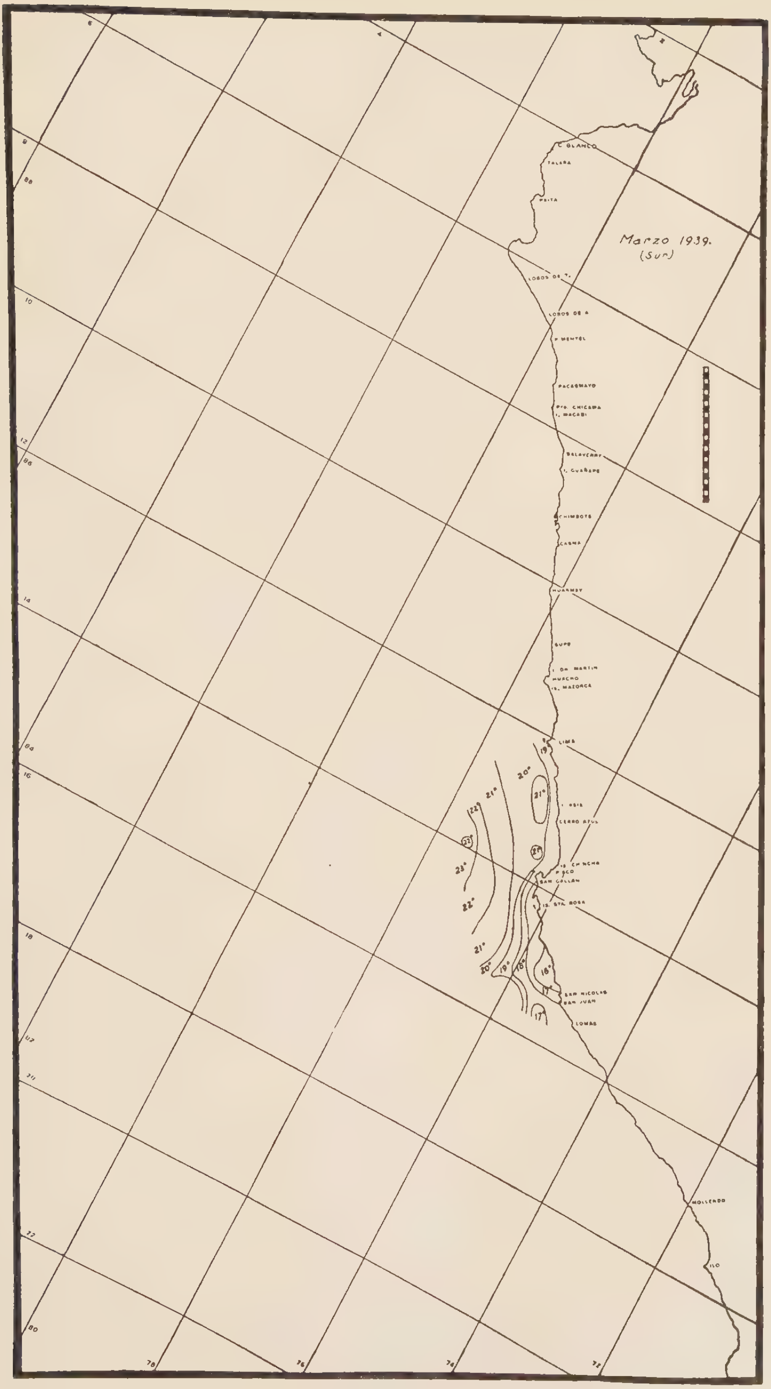
[2] We are indebted for these data to the kindness of Mr. Wagner, Chief of the National Meteorological Service of Lima.


Marzo 1939.
(Sur)
C. BLANCO
TALARA
PAITA
LOBOS DE T.
LOBOS DE A.
P MENTEL
PACASMAYO
PTO. CHICAMA
I. MACABI
SALAVERRY
I. GUAÑAPE
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CERRO AZUL
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IS. STA. ROSA
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LOMAS
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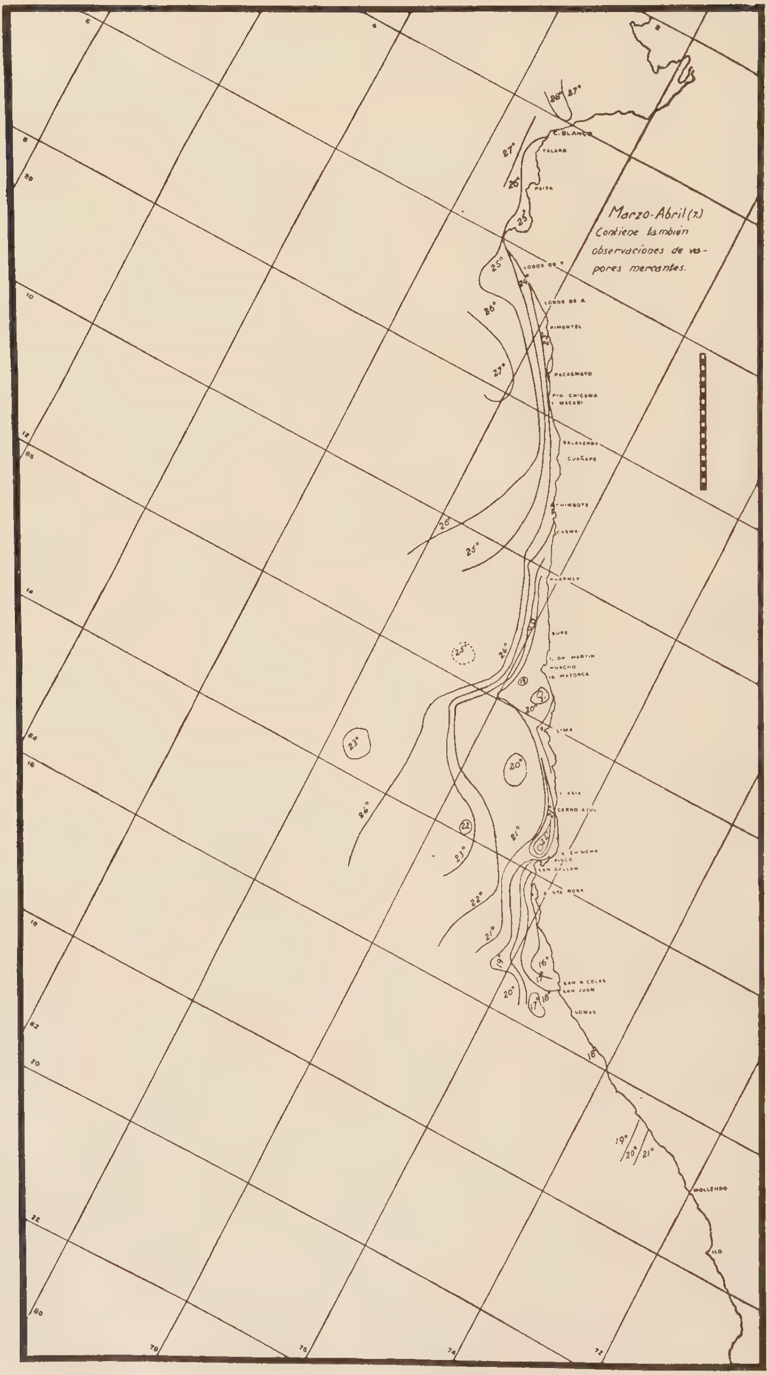
MAP 5


Marzo-Abril (7.)
Contiene también observaciones de vapores mercantes.
C. BLANCO
TALARA
PAITA
LOBOS DE T.
LOBOS DE A.
PIMENTEL
PACASMAYO
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CERRO AZUL
I. CHINCHA
PISCO
SAN GALLAN
STA. ROSA
SAN NICOLAS
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MAP 6

off Cerro Azul, extending almost to Pisco. Although as a rule this current is not very strong, on March 9 it made so much noise that it attracted attention for that reason alone. The current was carrying along branches of trees and shrubs, thus showing that it had had some contact with the coast, or rather, with the rivers which discharge their waters into the sea. This current had a temperature of 22°7.

On the night of March 8 the *Chincha* went from Callao to the island of Chincha and did not encounter a similar temperature at any point on its run, with two exceptions: first, a little south of the group of islands to the west of Callao—20°5, and second, more or less off Cerro Azul—20°9. During the whole night the temperatures stayed around 21°3, rising only 7 miles north of North Chincha island to 21°7. Between Center Chincha and South Chincha islands there entered a very strong current from the northwest, and at this point the temperature to the east of the Chincha island group rose to 24°1, to descend to 22°7 after a short run of 7 miles farther south (Ballestas Islands), and to 22°1 a little later.

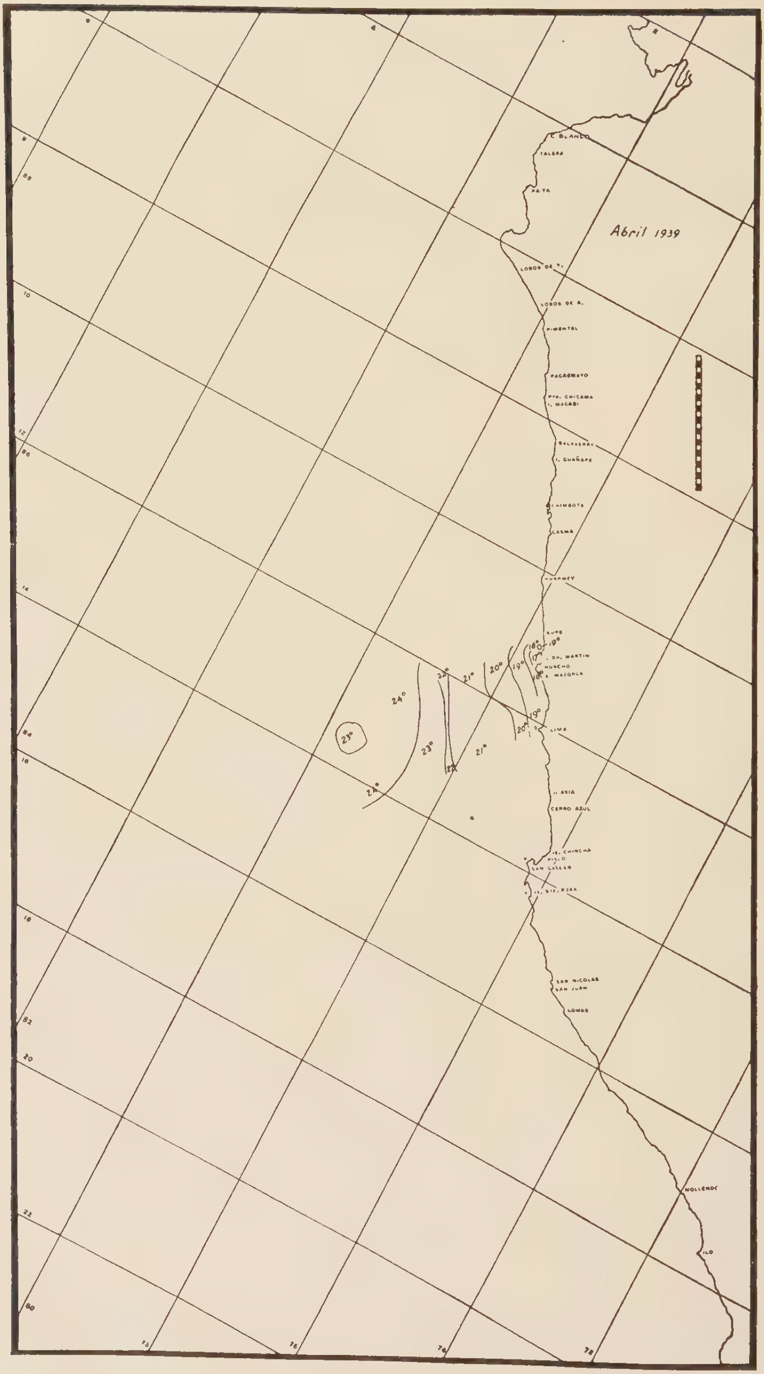
From all this we may conclude that the Bay of Pisco, prolonged to the south by the Bay of Paracas and closed at the south and southwest by the chain of islands comprising San Gallán, Ballestas, and Chincha, has its own local phenomena. An attempt is made to explain these phenomena in map 5, on which are shown the isotherms for March, 1939, in the section south of Lima.

On this map the 23° and 22° isotherms are easily explained, but not so the 21° isotherm. To the south-southeast of Callao the 21° temperature approaches to within 30 miles of the group of islands to the west of Callao, but to the south-southwest the limit of this temperature is 55 miles away from these islands. In the near vicinity of this group and only to the east of San Lorenzo was encountered the temperature of 19°, which was no doubt due to the influence of warmer waters in the Bay of Chorrillos, which register 22°. The 20° zone is also well localized south-southeast and south-southwest of San Lorenzo.

About three weeks later, another trip opened up a new sector extending to a distance of 280 miles from the coast in the postion of 14° 43′ S, 80° 23′ W (map 7). On leaving Callao the ship took a course a little more to the north than that of the *Chincha* on its return to San Lorenzo from the south-southwest on the night of March 14 (map 1, V). Comparing the determining points of the isotherms, it is to be noted that the 24° temperature is approximately 60 miles farther west than the most southern point of this line in the middle of February. But the 23° and 22° isotherms join very readily those obtained from the trip made in March.

They do not, however, make a simple connection with the isotherms obtained from the voyage made in February (map 4). The divergencies would easily be explained by a cooling of the waters, or, what is the same thing, a withdrawal of the warmer waters from the coast. But the readings taken by the merchant ships from the latter part of February to the 7th of April show the opposite (map 6); up to the end of March the warming of the waters progresses and the warm waters move nearer to the coast. This movement of the warm waters in the direction of the coast is more in evidence at the latitude of Salaverry.

Surely that wedge of 27° water which we observed on map 4, encountered to the west of Lobos de Afuera, has moved during the month of February and part of March in a southwesterly direction; indeed, this is proved by the temperatures in the region between Pacasmayo, the Lobos Islands, and Punta Aguja. Also 23° and 24° temperatures have approached from the southwest. All this prevents us from considering a cooling of the waters as an explanation of the irregularity of the isotherms to the south and southwest of Lima.


Abril 1939
C. BLANCO
TALARA
PAITA
LOBOS DE T.
LOBOS DE A.
PIMENTEL
PACASMAYO
PTO. CHICAMA
I. MACABI
SALAVERRY
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MAP 7

Nor does it seem to us possible to give a definite explanation with respect to these observations. But as we view all the phenomena occurring to the south of Lima as far as San Gallán, there is automatically presented the idea that there is some center of disturbance there which appears to be the cause of these irregularities. We must bear in mind the possibility that an eddy is formed there which brings cold water west from the coastal regions while at the same time a north–south current carries warm waters in the direction of the Bay of Pisco. Such an eddy, together with the upwelling caused by it, could explain the westward deviation of all the isotherms north of this location and also, perhaps, the unfavorable climate of Lima, unique on all the coast.

The supposed existence of this eddy would probably also explain the observation made on many trips that the temperature of 22° is restricted to a very narrow space, as shown by maps 3 and 4, less clearly by map 5, and very conspicuously by map 7. I would cite, for example, the observation taken at 1 A.M. of January 26, giving a temperature of 20.5°, and the observation of an hour later, after the ship had traversed only 8 miles, of 23.6°. Perhaps the cold waters transported by this eddy from the coast in a westerly and northwesterly direction meet the warm waters coming from the west in a direction toward the coast, and are still cold enough to reduce the natural area of the 22° and 23° waters on their eastern boundaries.

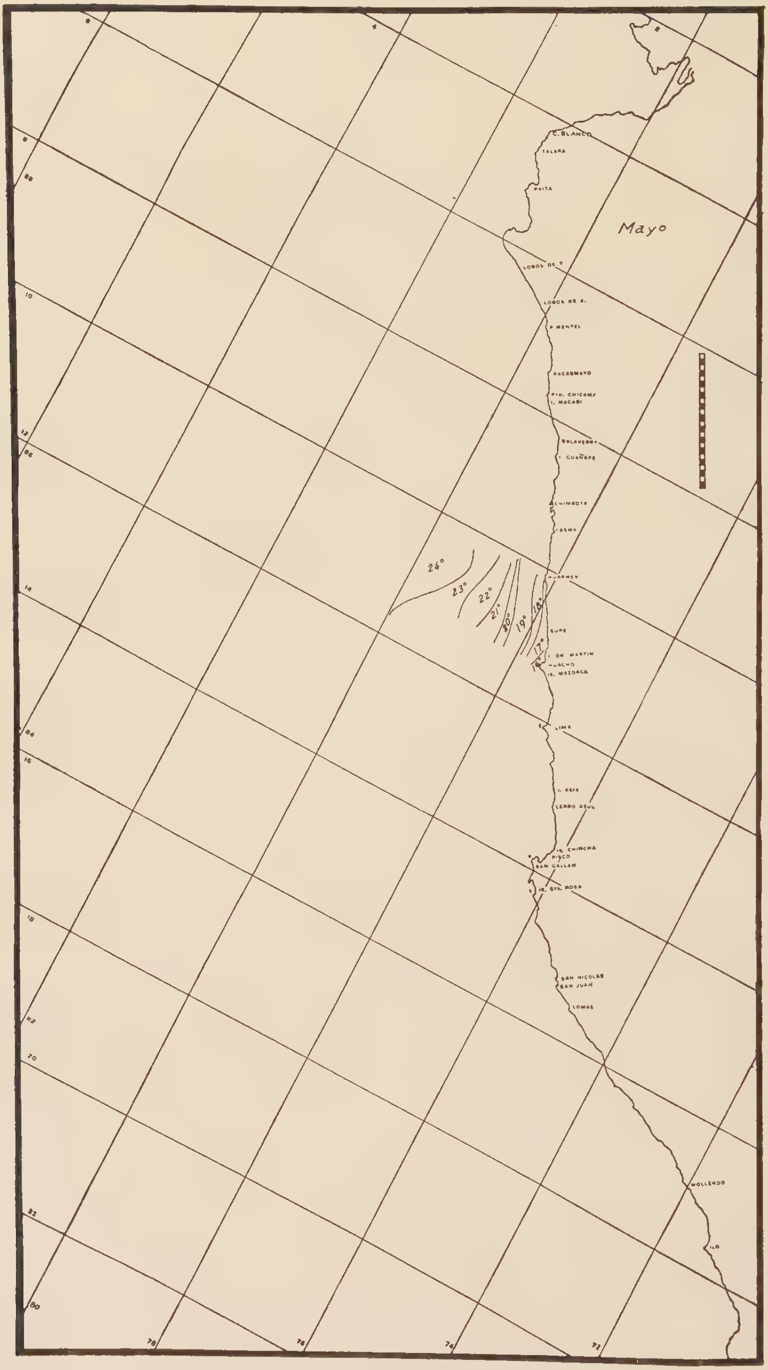
Map 8, based on observations obtained in the middle of May, shows the return of the warm waters to the west and the space occupied by the 22° temperatures more extended than on map 7. However, map 8 shows us the 22° temperatures more or less in the region where the map of Schott also shows them; but the 23° and 24° isotherms are still closer to the coast than those which Schott gives us for the culmination of normal summer.

With respect to the temperatures south of San Gallán—that is to say, to the south of latitude 14° S—we are still lacking sufficient knowledge to treat them more fully. What is always noticed is that the waters are surprisingly colder to the south of San Gallán than to the north of the island. On map 5 we have given the isotherms according to our experiences on the voyage in March. We could amplify the observations by measurements taken by the various merchant vessels navigating between Pisco and Mollendo, but as the course followed by these vessels is always close to the coast and almost the same as that taken by the *Chincha* on its voyage to Lomas, the temperatures observed by the merchant ships only confirm our observations.

The work of Gunther has already made known to us that in the region of San Juan there is a center of disturbance that affects all the sea over an extension which reaches at least to Arica. This center of disturbance makes it necessary to study maritime events on this part of the coast separately from that north of San Gallán.

From the observations made by merchant vessels off this coast it may be concluded that there existed two levels of temperature above the average level. It appears that the first occurs at about the middle of February and that the second becomes noticeable toward the end of April and in the early days of May. From the experiences of these merchant vessels it is shown that immediately to the south of San Gallán the temperature, as we have said, goes down, but that its minimum is found between 15° S and 16° S. From 16° S to Mollendo the temperature from all observations rises and remains a little higher than that immediately to the south of San Gallán.

All these maps, based on relatively scant observations, would not have been published if they had not demonstrated that something irregular occurred along the Peruvian coast this summer. It should be added that while during April the temperatures descended rapidly, during June they still remained


Mayo
C. BLANCO
TALARA
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MAP 8

exceptionally high for this time of the winter along the coast. But observations are still inadequate for the preparation of a map.

It yet remains for us to refer to the observations made on all voyages after having crossed the Peru Coastal Current and entered into the Peru Oceanic Current (according to the nomenclature of Gunther). The distinction between the two currents is very apparent, as Gunther observed, from the color of the waters. It is almost possible to regard the temperature of 23°.5 as that of the sea, which has a marine blue color, while between 23°.4 and 22° it has a milky marine blue, later mixing with green, and at 22° the dark green color known everywhere on the coast of Peru. The differences between the two zones of the sea are clearly distinguished from each other by meteorological as well as biological observations.

The plankton in the warm zone—which may be called the blue zone in contrast to the green or cooler zone—has suffered a decrease, as may be noted simply from the nocturnal phosphorescence of the sea, which is less in the blue zone than in the green. This phenomenon is produced in the blue zone by Ctenophores in the form of globules of half a centimeter in diameter. Larger-sized Ctenophores (?), as are nearly always observed in the phosphorescence of the green zone, are totally lacking as are also the Crustaceans (Amphipodes) which are frequently present in the plankton of the coastal zone.

In April the boat traveled through a part of the sea so full of Salpas in the form of little barrels that with each pail of water drawn up for measuring surface temperature there were four, five, or even eight of these little animals. The regularity of their appearance, which up till then had not been notable in the green zone of the coast, was limited to waters of 24°, or more than 23°.5.

A microscopic study of the plankton has thus far been impossible to carry out and is reserved for a future occasion; most of the investigations up to date have been merely macroscopic and superficial.

Sometimes whales were encountered in the blue zone; they are, however, also found occasionally near the coast.

Never did we encounter patches of fish as in the green zone, except isolated large sharks and rays. With a hook there were caught some dolphins, fish which do not exist in the green zone.

Most in evidence was the bird life. The blue zone is almost entirely depopulated in this respect. Occasionally were seen birds flying in twos, each dual group at considerable distance from the other. Expressed in terms of space, one could estimate the population roughly at two birds to every four or five miles. Nearly always there were observed, at least 70 miles away from the coast, isolated pairs of frigate birds (*Frigata magnificens*), although in February one of these birds made its appearance on the coast itself. Every time an increase in birds was observed, or groups of two noted closer together, it coincided with a decrease in water temperature, and the first flocks of birds were regularly encountered near a mixture of blue and green waters. Immediately after we entered the green zone, the number of birds increased and there appeared new varieties such as danzarinas (*Oceanodroma* sp.), pardelas (*Puffinus* sp.), and gulls.

Together with this increase in the bird population there was an increase in the amount of fish present. On one occasion, immediately after we had entered waters with a temperature lower than 22°, a shoal of fish was noted by the phosphorescence on the surface of the sea, but as it was at some distance off the course of the boat it was impossible to determine what kind they were.

All these observations are no more than confirmations of the differences between these two zones, also established in the work of Gunther.

Other differentiations, which perhaps could not be observed so clearly in

June as they could be this summer, are derived from the meteorological conditions. According to these, it can be said in general that upon leaving the coast, whether the latter be cloudy or clear, one arrives at a point 25 or 30 miles to the west where the sky is almost always clear both night and day and where one especially notes a complete calm.

This zone may extend itself to fairly near the coast (within about 10 miles), where the calm and the clear sky at night are especially well known.

With the change of color of the water one enters a zone with a southeast wind as on the coast, but one notices that this wind is warm and without humidity, at night as well as by day. The recording apparatus, for example, registers a relative humidity of nearly 100 per cent only between midnight and 2 or 3 o'clock in the morning, whereas in the green zone the humidity is at the saturation point almost from 10 o'clock at night to 6 in the morning. The wooden gunwales of the boats are wet during the night when crossing the green zone, which is not the case when sailing in the blue zone. In the latter it is possible to read the recording apparatus (thermometer, barometer, or hygrometer) every hour during the night, as their visibility is not obscured, but in the green zone it is always necessary to wipe off the glass in order to read after 10 o'clock at night. These facts demonstrate the difference in relative humidity between the two zones.

As we sailed from the coast in a westerly direction, the cold current was crossed in a clear zone, but as we entered the warm current the sky became covered with clouds driven by the wind, and at approximately 100 miles within the blue zone it began to rain in small but perceptible drops—whereas on the coast rain only appears as a drizzle (garúa).

The wind in the blue zone, as has been mentioned, blows from the southeast. During the voyage in April there was observed a change of wind from the southeast to a direction more to the east, which may be seen on the map showing the course of the boat (map 1, V) since the latter traveled without an especially determined route, taking the utmost advantage of the wind to reach the south and the west. Sailboats are more suited for making such observations than steamships, since the direction of the wind can be better determined with the former, while with the latter the movement of the vessel exercises an influence on all the means which might be used to determine the wind direction. The trip in the sailboat in the early part of May did not yield any observation of such a marked change in the wind, which kept blowing always from the southeast.

These winds move the clouds with their lower layer at a height of 250 to 300 meters, according to observations of temperatures and humidity. Above this layer other clouds are visible at great heights under the influence of winds from the north and northwest. This upper layer is surely that which is also observed on the coast beginning at a height of 900 meters.

As has been said above, the wind in the blue zone blows without interruption day and night, while in the green zone it usually calms down from about 8 P.M. till around 10 or 11 A.M. of the following day. It is also known that the first wind of the day as a general rule, blows from the south and also from the southwest on nearly all the coast, changing its direction later in the day more to the south and east, with preference to the south.

There is no doubt that the winds in the blue zone are derived from the high barometric pressure in the Southern Hemisphere and are the true and typical trade winds, this entire blue zone clearly presenting itself as a region governed by trade winds. The zone of calm, which separates this blue region from the green, seems to limit the direct influence of these trade winds and to leave the Peruvian coast under the influence of local winds, the directions of which are determined by meteorological events on the coast itself. On this coast the valleys have the effect of great chimneys which attract the wind after the upper cloud strata between 300 and 900 meters have been heated, while later in the day and during the early hours of the night this wind returns, falling from the Sierra toward the southeast, that is to say, along the principal direction of the Andes.

During the summer days, when the green zone off the coast was clear almost all day long, there could be seen far out at sea, especially at the hour of sunset, a dark bank of clouds which surely marks the limit of these blue-zone trade winds. On the northern part of the coast, particularly to the north of Huarmey (10° S), there was noted another phenomenon, which was observed for a long time and always with the same regularity not only from the coast itself, but also from an airplane. While to the south this bank of clouds maintained its relative height above the horizon, more to the north it descended to disappear more or less to the northwest or north-northwest of Puerto Chicama, so that seen from this port the sun was outside this cloud bank and remained visible to its last rays.

Lacking special observations on the prevailing winds in the sea area at a distance of some 60 miles off Puerto Chicama, we cannot yet offer a definite explanation. Map 6, however, seems to indicate that in this zone during that time there were winds from the north perhaps causing the distribution of waters with temperatures over 24°, which apparently approach less from the west than from the north or northwest of the coast. If it is permissible to accept this idea, the influence of these winds from the north would define the zone of the trade winds in their more northerly limits and would then explain the appearance of the bank of clouds which disappears slowly as seen from the coast, which is an expression of its withdrawal from the latter.

We have no doubt that all the observations set forth above refer to a special situation produced by the extraordinary summer of 1939 and make no pretense of being definite and valid for all the phenomena derived from the coastal and oceanic currents of Peru.

It remains for us to answer a question which would surely be formulated in connection with these observations. Why has it not rained this summer on the Peruvian coast? Yes, it has rained, but, according to the information which we have, only to the north of the Bay of Sechura (5° 30′ S) and on parts of the coast where a water temperature of over 24° came in close to shore. But to the south of Punta Aguja all the coast was protected by a belt of colder water, which is proved by the daily observations made in Puerto Chicama, where the temperature of the sea never exceeded 21°5. There exists a reference to Lobos de Afuera, an island which must have been surrounded by waters of 25°, according to which it rained there one night in the month of March.

It appears that the entrance of the warm waters of more than 24° from the north and northwest into areas to the north of the Peruvian coast corresponds to a development of the famous *"El Niño"* current as in the years 1891 and 1925, with the only difference that during the year 1939 this current did not have force enough to displace farther south the belt of cold water along this coast and to produce the serious damage which took place in the above mentioned years.

Immediately after having finished this report we received the very sad news of the sudden death of Mr. Guillermo A. Wagner, to whom reference has been made herein. He was a faithful friend and collaborator in connection with these studies and was intensely interested in the outcome of the reported investigations. His passing is deeply regretted by the writer of these lines.

THE OXYGEN CONTENT OF THE BOTTOM WATER IN THE INLAND SEAS OF THE ASIATIC-AUSTRALIAN ARCHIPELAGO

By P. M. VAN RIEL

ONE OF THE PAPERS of the *Snellius* expedition deals with the flow of the bottom water in the Indian Archipelago.[1] The inland seas in this area are separated from the adjacent oceans and from each other by submarine ridges, on which lie rows of larger and smaller islands and reefs with numerous passages. Much time was spent during the expedition in estimating by echo soundings the depth of these passages, as the properties of the abyssal waters in the various basins and troughs depend on the depth of the deepest entrance and the properties of the water *at that depth* outside the sill. This relation may help us to estimate the depth of the deepest entrance in a dividing ridge, by comparing, for instance, the numerous serial and bottom observations of potential temperature, inside and outside of the basin, carried out by the *Snellius*.

Based on these oceanographic considerations and on soundings, lines have been drawn on the chart (fig. 1) accompanying this paper, connecting the deepest entrances of the successive basins. The arrows show the direction of the flow of the bottom water and give an idea of the parts which the Pacific Ocean, the Indian Ocean, and the China Sea play in the renewal of the abyssal water layers in the isolated basins. The roman figures refer to table 1; below these figures have been printed the greatest depth recorded in the basin and the depth of its deepest entrance.

When this representation is correct, the distribution of the properties of the bottom water must point to a similar movement. The writer is now engaged in the adaptation of the bottom-water observations of temperature, salinity, and oxygen[2] and will give here some provisional results only as far as concerns the oxygen amount, estimated from water samples, obtained about 30 meters above the sea floor. This will be done by following up the arrows on the chart. Let us start in the Pacific Ocean.

The bottom water arrives from the Pacific Ocean into the Archipelago along three passages: (1) the entrance between the Philippines and the Talaud Islands, leading into the Sangihe trough (IV); (2) the entrance between the latter islands and the island of Halmahera, leading into the Morotai basin (VI); and (3) the entrance between the latter island and the island of Waigeo, leading into the Halmahera basin (XII).

The most important passage is that mentioned under (2). Here the Pacific water crosses the *Snellius* ridge at a depth of 2340 m. In the Morotai basin (VI) we observed near the bottom an oxygen amount of 3.06 ccm/L, corresponding with that at a depth of 2500 m. outside the ridge in the Pacific. The bottom water runs around the central ridge in the Molukken Sea to Gorontalo basin (X) and passes the Ternate trough (VII), 3.03 ccm., and Batjan basin (VIII), where the oxygen amount at Station 80 is rather low, 2.69 ccm. In the Gorontalo basin 2.88 ccm. has been observed.

From the Molukken Sea the bottom water crosses a sill at a depth of 1880 m. between the islands of Mangole and Obi and arrives in the Boeroe basin (XIII), which lies in the western part of the Ceram Sea. Here we found near the bottom an amount of 2.52 ccm., whilst at a depth of 1880 m., equal to that of the sill, we observed in the Batpan basin 2.54 ccm.

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[1] P. M. van Riel, The *Snellius* Expedition (Leiden, E. J. Brill), Vol. II, Oceanographic Results. p. 2, chap. ii, "The Bottom Configuration in Relation to the Flow of the Bottom Water."

[2] The results will be published in: *Snellius* Expedition, Vol. II, p. 5.

Between the Boeroe basin and the Banda Sea lies a ridge, connecting the islands of Boeroe and Sanana, 3130 m. below sea level. At this depth we observed in the Boeroe basin 2.56 ccm. at Station 229. From here the isoline for 2.50 ccm. crosses the sill in a tongue shape and reaches as far as the center of the northern Banda basin (XIV). Toward the south and east the amount decreases very slowly to, at the mean, 2.45–2.40 ccm. in the Southern Banda basin (XV), the Eastern Banda basin (XVI, Weber deep), and the small Ambalaoe basin (XVIII). The oxygen amount in the Banda Sea decreases toward the borders.

From the Weber deep (XVI) the bottom water crosses a sill at a depth of 2600 m. and arrives in the Wetar basin (XXV); the oxygen amount is, here near the bottom, 2.38 ccm., whilst 2.36 ccm. had been observed in the Weber deep at a depth equal to that of the sill. The water in the next depression, the Sawoe basin (XXIV), is renewed by that of the Wetar basin. Between them lies a ridge with a sill at a depth of 2100 m. East of this ridge we observed at this depth 2.36 ccm., an amount which decreases to 2.26 near the sill.

In the Sawoe basin the conditions differ from those in the Banda Sea, as a minimum of oxygen of 1.57 ccm. was observed in the center of the basin, the amount increasing toward the borders to about 2.00 ccm.

From the southern Banda basin a second branch runs along the bottom, crosses a sill at a depth of 2450 m., and arrives in the Flores Sea (XXII). Outside this sill the oxygen amount is, at this depth, 2.38 ccm., at the inner side near the bottom in the eastern part of the Flores basin, 2.28 ccm.

Let us consider now the passage mentioned under (1) south of the Philippines. Here a ridge separates the Sangihe trough (IV) from the Pacific Ocean at a depth of 2050 m. At this depth we observed in the ocean 2.61 ccm. at Station 265, whilst 2.73 ccm. was estimated from a bottom water sample in the Sangihe trough. The same amount was observed in the Ocean at 2200 m. depth.

From the Sangihe trough the bottom water runs along the deepest entrance toward the Celebes Sea, the depth of the sill being 1400 m. At this depth we estimated in the Sangihe trough 2.33 ccm.; in the Celebes Sea, however, considerably less. In this basin we meet the same conditions as those in the Sawoe basin, with a minimum of about 1.3 ccm. in the center of the southern part. Here also this amount increases toward the borders; just on the inner side of the above-mentioned sill 2.2 ccm. was observed at Station 297.

The third entrance leads from the Pacific into the Halmahera basin (XII). In the ocean the oxygen amount of the bottom water decreases toward the sill (depth 700 m.) from 3.5 to 2.9 ccm. Inside the basin we found near the bottom 2.92 ccm.

The part played by the Indian Ocean is limited to the renewal of the bottom water of the Timor trough (XXVI) and probably also of the Aroe basin (XIX). The dividing ridge between ocean and trough lies at a depth of 1940 m. The oxygen amount of the bottom water in the Indian Ocean decreases gradually toward the sill, from 4.2 to 3.0 ccm. We observed at Station 131, outside the sill at a depth of 1940 m., 3.26 ccm.; on the sill, 3.12 ccm.; and at the first deep Station (127) in the trough, 2.93 ccm. near the bottom. Farther inward the amount decreases gradually to 2.6 ccm. The conditions in the Aroe basin are rather confused; at two stations we observed near the bottom 2.16 ccm.

Temperature, salinity, and oxygen profiles along Sibutu Strait, connecting the Celebes Sea with the Sulu Sea, show clearly that no transport from the former to the latter exists. According to Chart 4200 of the United States Coast and Geodetic Survey, a sill at a depth of about 400 m. lies west of the island of Mindoro (Philippines). Across this shallow sill the deep layers in the Sulu Sea

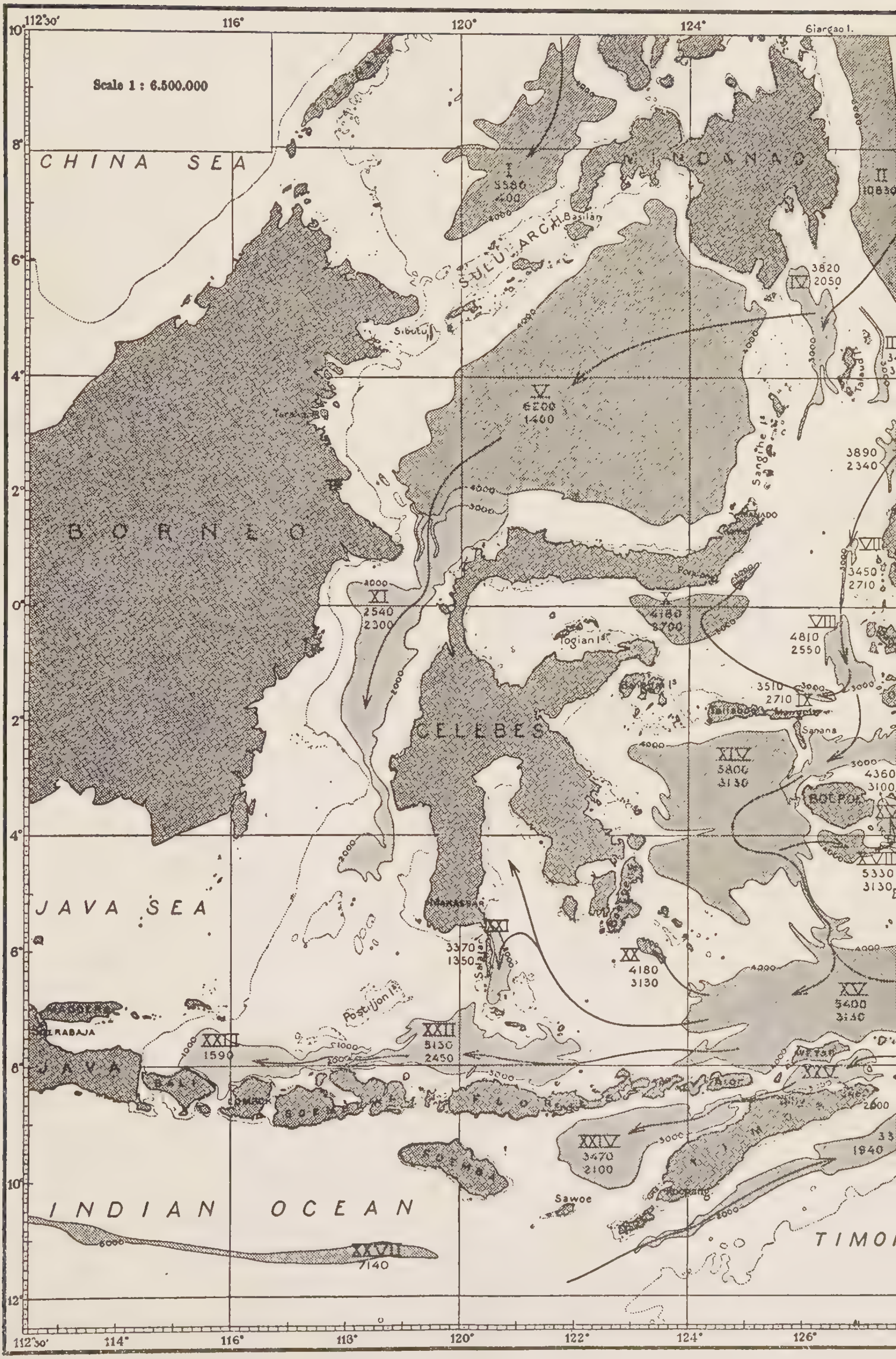
Scale 1 : 6.500.000
112°30'
116°
120°
124°
Siargao I.
CHINA SEA
MINDANAO
I
3586
400
II
10830
SULU ARCH
Basilan
Sibutu
Tarakan
3820
2050
IV
V
6200
1400
Talaud
Sangihe Is
3890
2340
BORNEO
Menado
XI
2540
2300
VI
4180
3700
VII
3450
2710
VIII
4810
2550
Togian Is
CELEBES
3510
2710
IX
Taliaboe
Sanana
XIV
5800
3130
4360
3100
BOEROE
XVII
5330
3130
JAVA SEA
Makassar
XXI
3370
1350
Saleier
XX
4180
3130
XV
5400
3130
Postiljon Is
Soerabaja
XXIII
1590
XXII
5130
2450
JAVA
BALI
LOMBOK
SOEMBAWA
FLORES
Alor
Wetar
XXV
XXIV
3470
2100
SOEMBA
Sawoe
Roti
TIMOR
1940
2600
INDIAN OCEAN
XXVII
7140
4000
3000
2000
6000
10°
8°
6°
4°
2°
0°
2°
4°
6°
8°
10°
12°
112°30'
114°
116°
118°
120°
122°
124°
126°

Fig. 1. Principal basins and troughs in the eastern part of the India

are renewed by water from the China Sea. The oxygen amount in this basin (I) is very low, namely, 0.47 ccm. in the center. From here the amount increases toward the southwestern and southeastern border to 1.5 ccm.

Still shallower is the sill separating Kaoe Bay from the Pacific Ocean. This bay is situated on the northeast side of the island of Halmahera at 1° N and 128° E. The maximum depth is 500 m.; the depth of the entrance, only 40 to 50 m. At Station 277 in the Pacific Ocean the oxygen amounts to 4.26 ccm. at a depth of 50 m., in the entrance to 4.04 ccm. at 35 m. The oxygen titrations of the water samples obtained in the bay showed that below 400 m. there was no oxygen present, and instead thereof traces of sulphureted hydrogen were

TABLE 1

BASINS AND TROUGHS IN THE EASTERN PART OF THE INDIAN ARCHIPELAGO

No.	Area	Sill depth (meters)	Greatest depth (meters)	Oxygen amount, ccm/L	
				Bottom water within basin	Outside basin at sill depth
			Pacific Ocean		
	Kaoe Bay[a]	45	500	*0.00*	4.26
VI	Morotai basin[a]	2340	3890	3.06	2.93
VII	Ternate trough	2710	3450	3.03	3.01
VIII	Batjan basin	2550	4810	2.69	3.03
X	Gorontalo basin	2700	4180	2.88	2.82
XIII	Boeroe basin	1880	5319	2.52	2.54
XIV	Northern Banda basin	3130	5800	2.50	2.56
XV	Southern Banda basin		5400	2.45	
XVI	Eastern Banda basin		7440	2.40	
XVIII	Ambalaoe basin		5330	2.40	
XVII	Manipa basin	3100	4360	2.42	2.49
XXV	Wetar basin	2600	3460	2.38	2.36
XXIV	Sawoe basin	2100	3470	*1.57*	2.36
XXII	Flores basin	2450	5130	2.28[b]	2.38
IV	Sangihe trough[a]	2050	3820	2.73	2.61
V	Celebes basin	1400	6220	*1.25*	2.33
XII	Halmahera basin[a]	700	2039	2.92	2.86
			Indian Ocean		
XXVI	Timor trough[c]	1940	3310	2.93	3.26
XIX	Aroe basin	1480	3680	2.16	....
			China Sea		
I	Sulu basin[d]	400	5580	*0.47*	....

[a] Direct connection with the Pacific Ocean.
[b] In the extreme eastern part of the basin.
[c] Direct connection with the Indian Ocean.
[d] Direct connection with the China sea.

observed. This bay offers a fine example of inadequate renewal of the depth water owing to the shallow entrance.

In this table the roman figures refer to the annexed chart. Under "sill depth" is given the depth of the deepest entrance. When the figures in the last two columns are compared it appears that the oxygen amount of the bottom water diverges in several basins only slightly from that observed outside the basin at a depth equal to that of the deepest entrance. The small difference in oxygen amount over an extensive area in the Banda Sea is strikingly in contrast with the conditions in the Sawoe, Sulu, and Celebes basins. The question arises whether the cause lies in a circular flow of the bottom water around the area of minimum oxygen, where the movement is very slow. Anyhow, the small amount of oxygen is also caused by shallow or narrow entrances.

THE FISH FAUNA OF THE PACIFIC OCEAN, WITH ESPECIAL REFERENCE TO ZOÖGEOGRAPHICAL REGIONS AND DISTRIBUTION AS THEY AFFECT THE INTERNATIONAL ASPECTS OF THE FISHERIES

By George S. Myers

My chief purpose is to outline the major faunal areas of the Pacific, as defined by fish distribution, and to point out a few of the implications that affect the conservation of species of economic value.

Before discussing the different regions it is necessary to say something about fishes and their habits. Since the time of the *Challenger* Expedition, ichthyologists have roughly classified marine fishes in three ecological groups, shore, pelagic, and deep-sea. Naturally this grouping is entirely inadequate, but as a primary division of the exceedingly complex picture of fish ecology it works fairly well. Shore fishes are taken to be those always occurring along coasts, never far out in the open deep sea, and generally found at depths of 100 fathoms or less. Pelagic fishes are those not confined to coastal waters, but often found far out in the open sea hundreds or thousands of miles from land and living generally at depths of 100 fathoms or less. With the deep-sea fishes are classed, indiscriminately, all those generally found deeper than 100 fathoms.[1] It is evident that shore fishes, by definition, must be limited in range by the extent of available coast line or archipelagos, and that vast areas of open deep ocean will prove to be barriers to them. On the other hand, deep open sea is a highway for the pelagic fishes. Many of the deep-sea fishes seem to obey distributional laws of their own, and since few economically important species are deep-sea forms, I shall not consider them here.

It has long been known that fishes are more abundant, in species and in individuals, near coasts than in the open sea. The shore fish fauna contains far more than half the known kinds of marine fishes; the deep-sea fauna is next, and the pelagic poorest of all. It is in the coastal waters, upon the continental shelves, that we find the most fishes, and therefore it is upon the continental shelves that we find the majority of commercially important fishes—the cods, flatfishes, croakers, sea-basses, mullets, salmon, and many others. In the pelagic fauna only two groups of great commercial importance exist, the mackerel- or tuna-like fishes and some of the herrings. Yet even these are likely to spend much time inshore, where food is most abundant. Some species, such as the Pacific sardine or pilchard, are hard to classify. They might equally well be placed with the shore or the pelagic division.

Tropical Shore Fish-Faunas in General

Before attempting to delimit or define the Pacific tropical faunas, it may be well to consider briefly the tropical marine fish faunas of the world. Ichthyologists have usually recognized in a general way four great tropical marine regions, the Indo-Pacific, the West African, the West Indian, and the Pacific American or Panamanian. They are all relatively distinct from each other in species and all have at least some distinctive genera. But all are remarkably similar in many respects, more similar indeed in the bulk than each is to the temperate faunas to the immediate north and south. This distinctness from the temperate faunas is of course obscured by the intermediate ranges of some species and through straying and the intermingling that always occurs. In spite of this, a careful elimination of stray-records and the sometimes extensive seasonal shifts of faunal boundaries will clear much of the obscurity and bring out the essential distinctiveness of the tropical faunas.

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[1] Some authors adopt a different depth (200 or 300 fathoms) but this is of little consequence in the present connection.

In every one of these four tropical regions the same genera appear—*Chaetodon, Pomacentrus, Abudefduf, Gymnothorax, Fistularia, Holocentrus, Apogon, Pseudogramma, Epinephelus, Lutianus, Upeneus, Thalassoma, Scarus, Balistes, Cantherines, Aleutera, Diodon, Chilomycterus, Callionymus, Antennarius,* and dozens of others—giving a characteristic similarity throughout. There is support for considering the tropical shore-fish fauna of the world as a unit. But if the more or less exact delimitation of marine zoögeographical regions serves any useful purpose, it is worth while to attempt to subdivide this fauna.

If one looks at a map of the world it is immediately evident that the eastern side of the great land mass of the Old World (Asia plus Africa) and the eastern side of the Americas show a vastly greater amount of tropical shore line and of tropical archipelagos than do the western sides. Moreover, the mean annual isotherms of surface water temperature show that the really warm parts of the ocean (80° F.) are greatly expanded to the east and contracted to the west of the continental land masses. This is, in large part, due to the equatorward drift of the cool California and Humboldt currents in the eastern Pacific and the Canaries and Benguela currents in the eastern Atlantic. We should, therefore, expect the tropical fish faunas of the western Pacific–Indian Ocean and the Caribbean areas to be larger and more varied than those of Pacific America and Atlantic Africa. Little examination of the faunas is necessary to show that this is true.

The West Africa fauna has recently been monographed by Fowler (1936). While the shore fishes are still very incompletely known, and considerable additions to the list may be expected, the truly tropical West African shore fish fauna appears to be comparatively small. The Mediterranean element, only a small part of which is undeniably tropical, comes far down and seems to be dominant at least as far as Senegal. A number of shore species or genera are held in common with the West Indies, but some of these are circumtropical forms, probably of considerable age. A few Indo-Pacific families or genera not found in the West Indies are represented by single species (*Drepane, Periophthalmus,* Monodactylidae, Psettodidae, Platycephalidae) that might conceivably have come recently via the Cape. Of endemic families there appear to be only two small ones (Heterenchelyidae, Myrocongridae), and endemic genera are few.[2]

The West Indian, or Caribbean, fish fauna, extending from southern Florida and Atlantic Panama to Bahia, is very large and rich, and contains two-thirds or more of the truly tropical shore families found in the Indo-Pacific. Nearly all the genera and species of such families are much fewer in the West Indies than in the Indo-Pacific, and, except for a few circumtropical forms, the species of the two regions are entirely distinct. Endemic genera are rather numerous. There are, however, very few endemic families; only one (Acanthenchelyidae) seems to be confined to the area. A very few other families (Chaenopsidae, Dactyloscopidae) are apparently autochthonous West Indian groups but are now found also in the Panamanian fauna. Although much work has been done in the West Indian region, the collecting has been poorer than most ichthyologists realize and large additions to the fauna are bound to be made. It is only recently, for example, that the families Cirrhitidae and Anomalopidae and the circumtropical genus *Pseudogramma* were found in the Caribbean, and modern methods of collecting small shore fishes have been used only rarely.

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[2] One family, perhaps not strictly tropical, that should be mentioned in this connection is the Parapercidae (including the Pteropsaridae). They are common in the tropical Indo-Pacific and in Japan and Australia; one species *Chilias nebulosa,* reaches as far south as Natal, in East Africa. The single West Indian form, called *Hypsicometes gobioides,* is said by Alcock to be identical with the Indo-Pacific *Bembrops caudimacula!* Yet no fish of this type has turned up in the Panamanian or West African fauna, despite much deep-sea dredging. However, there is a Parapercid of another genus recorded from Cape Verde Islands, although it is not mentioned by Fowler (1936). It is *Neopercis atlanticus* (Vaillant, 1887).

INDO-PACIFIC

By far the richest of the four tropical shore fish faunas is the Indo-Pacific, *and it contains practically all the families and a considerable number of the genera that make up the fauna of the other three, in addition to many families and genera not found elsewhere.* Only a few such unimportant groups as the Nematistiidae, the Microdesmidae, the Mycrocongridae, and the Dactyloscopidae, out of all the families of tropical marine fishes, are absent in the Indo-Pacific. When we add the fact that this fauna extends unbroken from East Africa and the Red Sea to the Tuamotus, more than halfway around the world, we begin to realize that the Indo-Pacific is, itself and alone, the great world fish fauna of the tropics, and that *these other three are nothing but depauperate minor geographical segregates of it,* cut off by present continental lines from the main tropical fauna. Fish distribution gives considerable support to Austin Clark's contention that the Atlantic is, biologically, an inland sea (Clark, 1914). It is evident, therefore, that so far as family groups go, the other tropical fish faunas are defined largely by the Indo-Pacific groups they lack, rather than upon positive characters.

The geographical boundaries of the Indo-Pacific shore fish fauna are, in general, the area from Natal to the head of the Red Sea and the coasts and islands eastward to the Tuamotus and Hawaii, north to Kiushiu and Chekiang, and south to the Great Barrier Reef and New Caledonia. For reasons already given, its exact boundaries are hard to place, but the boundaries of the true Indo-Pacific fish fauna, like those of the other tropical faunas, are perhaps best defined by the range of the parrot-fishes of the genus *Scarus,* or the extent of reef coral.

The homogeneity of the Indo-Pacific fauna is at once apparent from the fact that great numbers of shore species exist from one end to the other of it, the records of capture running from the Red Sea and Delagoa Bay to Honolulu, Tahiti, and Okinawa. Ranges of this type are found not only in the larger fishes but also in such tiny ones as *Kraemeria.* That there are subareas of endemism, however, is apparent, since many of the species appear to be confined to relatively circumscribed regions. Yet the area is so vast and the collecting has been so sporadic that an apparently restricted range of any fish within the region should be looked upon with suspicion. Really intensive prolonged collecting of the shore fishes of the Indo-Pacific, by competent ichthyologists, has been carried on only in certain parts of the Philippines and at a few other spots, such as Okinawa and Samoa, mostly by three Americans, Jordan, Snyder, and Herre, and by the U. S. S. *Albatross* in the Philippines. The coasts of the Netherlands East Indies, most of Oceania, northern Australia, and the shores of the whole of India and tropical East Africa have never been properly and intensively fished, even at one locality. I have just mentioned *Kraemeria.* It was obtained by Jordan at Samoa and by Gardiner at Praslin Reef in the Seychelles. Later, Cooke obtained it on several of the Hawaiian Islands. No other localities are known, yet this tiny fish probably exists by the thousands on warm sandy beaches from Zanzibar twelve thousand miles around the globe to Nukuhiva.

Some of the Indo-Pacific shore species very definitely do not range widely. For example, the almost cosmopolitan warm-water family Sciaenidae, the croakers, have here, as elsewhere, moderately restricted coastal ranges. But the croakers, like other groups, are confined to the coastal waters of large land masses, where the estuaries of large rivers are to be found. They do not extend out into Oceania at all, in spite of the fact that they are abundant in genera and species along the coasts of the continent and the Malay Archipelago. And there are definite areas of endemism apart from such fishes as the Sciaenids. The Hawaiian group has a number of species of shore fishes that are recognizably different from those of the rest of Oceania, and even what appear to be some distinctive genera. Within the main region itself, there are doubtless fairly distinctive subregions that could be defined even on the basis of available data, but our painful lack of knowledge of distributional data makes such definition difficult.[3]

The tropical Indo-Pacific is marked by many families not found in the other tropical divisions, as I have mentioned above. Among them are the families Chirocentridae, Neenchelyidae, Solenostomidae, Centriscidae, Menidae, Lactariidae, Ambassidae, Plesiopidae, Letrinidae, Sillaginidae, Cepolidae, Siganidae, Scatophagidae, Trichonotidae, Xiphasiidae, and Triodontidae. Others, such as the Chanidae and Kuhliidae,[4] are purely Indo-Pacific, but have recently managed to reach the Panamanian fauna. A host of genera are also diagnostic of the Indo-Pacific, a few prominent ones being *Caesio, Amphiprion, Epibulus, Gomphosus, Cheilinus, Naso, Zanclus, Heniochus, Centrogenys, Chromileptes, Pseudochromis, Scolopsis, Pentapodus, Therapon,* and *Triacanthus.*

A word must be said of the fresh-water fishes of the islands of the Indo-Pacific. The large continental islands—Ceylon, Sumatra, Java, Borneo—have a continental fauna, but east of Wallace's Line true fresh-water fishes drop out quickly. Oceania has none, except for introduced forms, and the fishes of the island rivers may, for nearly all purposes of distribution, be considered as marine shore forms.

Panamanian

The Panamanian fish fauna extends from the Gulf of California to Ecuador; it is best known and probably reaches its acme in Panama Bay.[5] The fauna is typically West Indian. Meek and Hildebrand (1923–1928) list 72 species common to the Atlantic and Pacific sides of the isthmus, of which 48 are more or less circumtropical. This, however, does not take into account the large number of closely related vicarious species. Comparatively few genera not held in common with the West Indian fauna are present, and it is plainly evident that a strait existed across the isthmus, perhaps not earlier than the Pliocene. Since I have already remarked that the West Indian shore species almost all differ from their Indo-Pacific relatives, it will be evident that the Panamanian fauna is trenchantly distinct from the Indo-Pacific. In fact, as Ekman says, the wide area of deep water between Polynesia and the West American coast forms the sharpest existing break in the circumtropical shore fauna. Pelagic species are the only ones that commonly bridge it in their ranges. The fact that a few

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[3] Another factor that must be considered is the state of the classification of Indo-Pacific tropical fishes. Few of the groups have been subjected to careful revision and most of those not recently. The more brightly colored forms have been classified traditionally by color to the neglect of anatomy, and the general level of quality of systematic work on Indo-Pacific fishes is low.

[4] The West African *Parakuhlia* does not seem to belong to this family. Its described characters approach those of *Centrarchops,* a Serranid.

[5] The Galápagos Islands contain a number of Panamanian forms, but the rather poor shore fish fauna has perhaps as much in common with the temperate South American fish fauna. A number of Indo-Pacific forms have reached the Archipelago and are found nowhere else in America save Cocos Island. Fowler (1938) has listed the fishes.

Indo-Pacific shore forms have reached the Galápagos, Cocos, and the Revillagigedo Islands, and still fewer have gotten to the American mainland, is of little consequence, since they are so plainly evident that their fewness is very apparent. *Kuhlia, Holotrachys, Forcipiger, Zanclus, Acanthurus triostegus, A. aliala,* and others have reached the offshore islands, while *Petroscirtes* (=*Runula*), *Doryrhamphus,* and *Chanos* are established on the mainland.[6]

The Panamanian fauna is poorer than the West Indian, lacking such forms as the Moringuidae, Megalopidae, Aulostimidae, and Erythroclidae (Inermiidae), but it is as yet poorly explored. One family, the Nematistiidae, and a number of genera are endemic.

NORTH PACIFIC

In placing all the Pacific north of the tropical faunas in one division I realize that there is much to be said for further splitting, but as a primary fauna I believe it deserves to appear as a unit. While a large proportion of the shore fishes of California are generically distinct from those in temperate Japan, the resemblances are, to me, even more striking than the differences, and any definable "Californian" shore fauna would be made up mostly of forms related directly to either Panamanian or undeniably North Pacific species. California, like temperate Japan, is a transition zone, but the picture is complicated by the warm Kurosiwo and the cold California current. In general the true North Pacific fishes therefore range farther south along the American than the Asiatic coast, with the exception of the mainland coast of the Japan Sea.

The North Pacific is characterized most notably by an unrivaled diversity of the mail-cheeked fishes, the Scorpaenidae, Cottidae, Liparidae, and Agonidae, and the development of several distinctive endemic families of this order, among them the Hexagrammidae, Anoplopomatidae, and Rhamphocottidae. Other endemic families are the surf-perches (Embiotocidae), the Zaproridae, Trichodontidae, Aulorhynchidae, Bathymasteridae, and Ptilichthyidae. Large numbers of genera of all groups are found nowhere else. The closest relationship is with the north Atlantic and Arctic, as would be expected.

TEMPERATE SOUTH PACIFIC

In taking up the temperate South Pacific faunas, I proceed with some hesitation. I have seen alive and have worked with the fishes of only one small section of this area, Coastal Peru, and less is known of the fishes of southwestern South America than of those of any other major part of the Pacific. As a matter of fact, the international aspects of fish distribution and conservation are far less important in the South Temperate Pacific than in the North.

The Australian–New Zealand shore fish fauna shows a large element of Indo-Pacific forms, caused by the southward extension of warm water along the Queensland and New South Wales coast. After weeding out these forms there is left a typical south temperate fauna closely related to those of south temperate South America and South Africa. In all these faunas many north temperate genera, and sometimes species, appear. This discontinuous "bipolar" distribution is a well-known phenomenon. Some of the identical north-and-south species *may* be able to cross the equatorial belt of warm water, but most of them surely cannot.

The Australian–New Zealand fauna is characterized by a number of endemic genera and by a few distinctive families—the Leptoscopidae, Odacidae, Pataecidae, Brachionichthyidae, and Limnichthyidae. But relationship with Chilean and antarctic forms is very evident, especially in New Zealand.

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[6] The Heterocongridae would appear to have a similar distribution, but I rather expect "gardens" of these queer eels to be discovered in the Caribbean.

The temperate West South American fauna is very poorly explored north of the northern boundary of the Patagonian fauna. With some misgivings I place the northern boundary just below the Guayas estuary at Cape Aguja, since my brief collecting experience in Peru and Ecuador shows that the sharpest faunal break between the Panamanian and temperate faunas occurs somewhere near this point. The fishes at Callao show that the fauna is still a transition one even there, but most of the typically tropical forms are absent. Southward, Regan and Norman place the beginning of the Patagonian fish fauna at Chiloe.

The Chilean fauna, as it is sometimes termed, has few strikingly characteristic endemic forms, but is composed of a number of groups common to Atlantic Patagonia, a noticeable Australian element, and a large admixture of tropical forms at the north, and Patagonian ones at the south, in addition to the groups common to all south temperate faunas.[7]

Pelagic Species

Something must be said of the pelagic species such as the tunas and swordfishes. I have already mentioned that they do not obey the distributional laws of shore fishes, and at least some of the species appear to migrate through areas of very different temperature conditions. With the tunas and swordfishes, this apparent indifference to temperature changes that are barriers to other fishes may have some relation to the fact that they are warm-blooded creatures, maintaining a body temperature often as high as 10° F. above that of the surrounding water. No one knows their life histories; they come, stay awhile, and are gone. Their spawning places are a mystery, and young examples, at least of the tunas, are practically unknown. The adults are usually too big to permit museum examination and we do not yet know whether the species of Japan are the same as those of California, or whether either are the same as those of Oceania. At first sight, it seems that most of the species have enormous ranges or annual migrations, but recent chemical studies of the liver oils tend to show that the Japanese and American forms of some species may be distinct. I am inclined to think that both the Japanese and the West American tunas spawn in tropical Oceania and I have one report of ripe individuals in eastern Polynesia. Perhaps, if the American and Asiatic species are distinct, both spawn in the same general area, like the Atlantic eels. What appear to be the same species are common in New Zealand and Australian waters and I have no doubt they are to be found off Chile, where few have fished for them.

Importance of Fish Distribution in Conservation

It may seem that fish distribution and the delimiting of faunal regions has little to do with the practical matters of fisheries research and conservation. The fact that many fishery biologists never give much thought to any possible connection between these subjects is, I believe, a corollary of the geographical distribution of fishery biologists. The great majority of them belong to the temperate zone of the North Atlantic or North Pacific but are totally unaware of their own faunal provincialism. It is only those few who transfer to the tropics or Southern Hemisphere who become fauna-conscious.

Actually, to a fishery researcher in the midst of a great faunal zone, the boundaries of that zone become important only when the species with which he is concerned ranges to its borders, or beyond. A good example is the California sardine, or pilchard (*Sardinops*). These sardines occur not only along the temperate North American coast but also in the temperate Asiatic, Australian, South American, and South African faunas. Dr. Walford and I are unable to tell apart specimens from any of these five regions save the Australian. Australian examples seem to differ slightly but constantly, and form one species (*S. neopilchardus*), while all the others seem to be referable to *S. sagax*. Depletion of the California supply and attendant conservation efforts make it extremely important to know whether the four great populations of *S. sagax* can have any communication across sharp faunal boundaries. If they can, the drain on one population might be relieved by migration or infiltration from distant sources.

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[7] I am omitting entirely the Patagonian and Antarctic faunas.

Speaking as one who is not a sardine biologist but who has gone rather extensively into faunal distribution, I believe it extremely unlikely that a surface-swimming, semipelagic fish inhabiting as cool water as does this sardine, could pass the equatorial regions, and I think that the southern temperate *Sardinops* never have communication with the northern populations. On the other hand, the Japanese and California population are in the same fish fauna, and I believe that there may be sporadic if not extensive intermingling in the North Pacific.

Matters such as these lend point to a study of marine faunal areas in considering the broad subject of fish conservation and the probabilities of the extent of the area that must be covered by united international effort to conserve a certain species or set of species. Within a zoögeographic region, extension of the range or migrations of a particular species are to be looked for anywhere. Across a zoögeographic boundary, the chances of intermingling of the shore fishes are greatly reduced. For all practical purposes, then, international coöperation in conservation of all except the pelagic fishes is vitally necessary only *within* definite major zoögeographic regions.

The evidence is plain and unavoidable, even to the weakest intellect, that the natural distribution of living creatures bears no relation whatsoever to political boundaries or manmade laws. Except where one nation possesses a large coast line, few marine fishes live exclusively in waters claimed by a single government, and where the range of a particular fish species extends beyond the jurisdiction of one government it is practically certain that part or all of the population of that species moves back and forth indiscriminately across the jurisdictional boundary or boundaries involved. *Within any one of the major zoögeographical divisions I have outlined*, any particular species of fish is likely to move about, either as adult migrations or as floating eggs or larvae, over immense areas, and a depletion in one place may be taken up by the species over its entire range thus lessening the chances of severe local depletion. On the other hand, depletion at one point may severely affect the species as a whole, as in migrating forms. With the pelagic tunas, fishing in one place may possibly affect the population over the entire Pacific. We know, of course, that many species are fairly stationary, at least when adult, and this is of great importance, since if the population is depleted at one point, recovery there may be slow.

It is clear that a great many species of marine fishes, perhaps the majority, have "international" ranges and that perhaps the majority of commercially important species transcend the seaward jurisdiction of nations, whether it be the "three-mile limit" erroneously supposed to be fixed by international law[8] or any other artificial limit. In such species, conservation measures designed to insure the best possible continuous catch must be of an international nature, to protect against nullification of regulations by unrestricted fishing either on an adjoining coast under different sovereignty or at sea beyond the limit claimed for fisheries protection. Unfortunately, it is often difficult to promulgate such international regulations, since they are usually attempted for the benefit of single species, and with any single species the regulations *obviously soundest biologically* are apt to seem unfairly favorable to a single nation. If broader general agreements could be drawn up, to cover many species, the reciprocal benefits would be more easily appreciated.

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[8] See Bingham, 1938.

This leads to my final point. The greatest obstacle to the enactment of really effective conservation measures, particularly those of an international nature, is frequently the inability of legislators or diplomats to comprehend the necessity or reciprocal value of regulations proposed by fishery biologists. The intricacies of biological knowledge of even a single species are seldom entirely reducible to terms intelligible to nonbiologists, yet a single obscure point may be of critical importance to conservation. In international dealings, the diplomatic representatives of one power are apt to be adamant in demanding "favorable" modification of treaty clauses because the original terms would mean a temporary or permanent lowering of the catch of their own nationals, however vital the original terms might be to the future existence of the fishery. Frequently they are entirely dominated by commercial interests which understand nothing of the permanent value of conservation measures to themselves, and are entirely unaware that the really competent and unbiased fishery biologists of their own nation might favor the opposite point of view.

This being the case, it would seem obvious that an international board of fishery biologists, representing all the nations having a coast line within a major marine zoögeographic region, might act as a powerful instrument of propaganda leading to the adoption of sound international measures for the study and regulation of marine fish conservation. Moreover, if we can expect international good sense to exist in this world, such a board might grow to become the official and final diplomatic arbiter of international fisheries problems. We sincerely hope for such an end.

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DISTRIBUTION OF THE MACKEREL-LIKE FISHES IN THE WESTERN PACIFIC NORTH OF THE EQUATOR

By Albert W. C. T. Herre

The mackerel-like fishes fall naturally into several families, all closely related and easily recognized. Of these, the *Scombridae* or mackerels proper, the *Thunnidae* or tuna family, the *Gempylidae* or snake mackerels, the *Trichiuridae* or hair-tails, the *Istiophoridae* or sail-fishes and spear-fishes, and the *Xiphiidae* or swordfishes are widely distributed in the western Pacific, and a number of them occur in very great abundance.

The mackerel-like fishes are exceeded in abundance and importance only by the *Clupeidae* or herring-like fishes. This is particularly true of the region north of Formosa, while over the whole of the western Pacific they are of great importance. The *Scombridae* proper include but few genera and species in the territory here considered. *Pneaumatophorus japonicus* is common over most of the western Pacific, from Japan and Korea to Hawaii, and southward throughout. Sometimes 2,000,000 mackerel are landed at one Korean port in a single day. South of Formosa the Japan mackerel is largely replaced by deeper-bodied mackerels of the genus *Rastrelliger,* chiefly if not entirely *R. brachysoma, R. kanagurta,* and *R. loo.* These kinds are caught in large numbers in the Philippines and southward and eastward in the East Indies and Polynesia, and westward into the Indian Ocean.

Other genera formerly placed under the *Scombridae* might better be removed to the *Thunnidae.* The following fishes, here regarded as members of the *Thunnidae,* occur in the western Pacific: *Thunnus thynnus,* the bluefin tuna; *Neothunnus macropterus,* the yellowfin tuna; *Neothunnus rarus; Euthynnus yaito; Katsuwonis pelamis,* the oceanic bonito; *Germo alalunga,* the albacore; *Parathunnus sibi; Sarda orientalis,* the skipjack; *Gymosarda nuda,* the surf tuna; *Auxis thazard* and one or two other species of frigate mackerels; *Scomberomorus commerson,* the seer fish or Spanish mackerel, and several other closely related species, namely, *S. chinensis, S. niphonius, S. koreanus,* and *Scomberomorus guttatus,* or the Chinese, Japanese, Korean, and spotted seer fishes; *Acanthocybium solandri,* the peto or kingfish, and *A. forbesi,* or Forbes' kingfish; and *Grammatorcynus bicarinatus,* the two-lined kingfish.

Whether *Euthynnus alleterata,* the Atlantic or striped bonito, occurs in the Pacific, is not clear to me. Jenkins, Jordan, Fowler, Gunther, and others have recorded it from the tropical Pacific, all the way from Tahiti, Australia, and Hawaii to New Guinea and Japan, but the very few specimens I have been able to examine critically have proved to be *Euthynnus yaito.* However, I have not examined Polynesian or Australian specimens, but have seen in Polynesia fishes which I thought were probably *E. alleterata,* but which may well have been *E. yaito* like the Philippine examples.

Nearly all the species of *Thunnidae* named above occur over the western Pacific from the South China and Celebes Seas, and the waters north of New Guinea, northward to Japan proper, and eastward to the Hawaiian Islands. Their distribution south of the equator is outside the topic assigned, as is also the distribution of those occurring on the American coast and in the Atlantic. *Neothunnus rarus,* which Kishinouye supposed was Japanese and Formosan, I have obtained as far south as Singapore.

Some of the tunas and bonitos mentioned above occur in enormous schools containing a vast number of individuals. I have seen schools of *Katsuwonis pelamis* and *Euthynnus yaito* in the Philippines which would have fed every one for a week in a city as large as Manila or Seattle. But such schools are insignificant beside one of the oceanic bonito reported off the north coast of Oahu which was 90 miles long by 10 broad.

Vast quantities of the oceanic bonito are caught in Japanese waters, from Hokkaidô in the north to the Riu Kiu Islands and Formosa in the south. It is also taken in large numbers in the Japanese-owned Pelew and Caroline islands, and in the Hawaiian Islands. In the last few years the Japanese have extended their bonito fisheries greatly. As long ago as 1922–23, research vessels from Formosa explored for the oceanic bonito around the Philippines, Borneo, and Celebes, at least as far south as the equator. Since then the region between the Pelews, Carolines, and Marshall Islands on the north and New Guinea and the Moluccas on the south has likewise been explored. While a great deal of information was naturally obtained concerning other fisheries and their potentialities, the primary purpose was the expansion of oceanic bonito fisheries.

The bluefin tuna occurs generally throughout the western Pacific, but is more important commercially in Japan than elsewhere in this region, because it is the commonest of the group in Japanese waters. It is found throughout the year off the coasts of Japan, in summer migrating as far north as latitude 46 degrees, or approximately the southern end of Sakhalien. Apparently the bluefin resorts more to the coast of Japan than to the tropical waters of the western Pacific, although it is taken also off the southeastern coast of Mindanao. In Japan many are taken in pound nets and fish corrals, as well as with drift nets and long lines, while elsewhere they are apparently taken only with hook-and-line fishing.

In warmer waters the yellowfin tuna is very widely distributed. It is the most abundant and therefore the most important of the tunas from southern Japan, and the Riu Kiu and Bonin islands, southward to the equator. Enormous schools occur from the southern Philippines southward and eastward throughout the region north of New Guinea, thence eastward and southeast through Polynesia and northeast to the Hawaiian Islands.

The Yaito tuna, a small fish rarely reaching a weight of 10 kilos, is widespread also in the western Pacific. It is taken in fish corrals in the Philippines, and with hook and line there and elsewhere. The yellowfin and yaito are caught commercially in great quantities about Formosa, the Philippines, and British North Borneo; large numbers of the yellowfin tuna are also taken in Hawaiian waters.

It is uncertain whether Japan actually cans tuna or not in Japan proper, but unquestionably nearly all tuna, whether bluefin, yellowfin, or other kinds, taken in Japanese home waters, or north of Borneo, are eaten fresh. Some are smoked, and in some seasons a good many tons are shipped to the tuna canners of San Pedro, California.

The only western Pacific tuna canneries outside Japan are one at Si Amil, British North Borneo, which has been in operation since 1928, and a smaller one at Zamboanga, Mindanao, P. I., which was opened about two years ago. Both are operated by Japanese. A great many tuna and bonito are caught in northern Philippine waters, about the Babuyanes and Batanes islands, by poachers from Formosa.

The capture and canning of tuna could be much more developed in Philippine waters and in the Dutch East Indies, where as yet nothing has been done to utilize them by modern methods. Within the last two or three years Japanese fishermen have begun to catch tuna in the Gulf of Davao, Mindanao, by the use of long lines, and by pole and line, the catch being sold fresh. Tuna and bonito are also caught by trolling, in fish corrals, and in seines. The fish caught by native methods (i.e., by Filipinos) are either eaten fresh or cut into slices and dried. Fish taken off the Lubang Islands and other points in that general region are often placed in cold storage in Manila until the rainy season; then as storms prevent fishermen from obtaining the usual supply of fresh fish the cold-storage tunas are sold very quickly.

The tuna catch of Japanese fishermen is almost entirely eaten fresh, as already stated, with the exception of that used by the canneries in Si Amil and Zamboanga, already mentioned. This is true for all kinds of tuna, and also albacore. The chief interest Japanese have in the tuna family in foreign waters is in the catch of oceanic bonito; therefore every effort is made to obtain bonito and prepare the flesh as *katsuwobushi.* For this bonito are cut longitudinally into four pieces, boiled until partly cooked, and then smoked and dried. The resultant product is very hard; the large pieces are cut into smaller pieces which resemble somewhat one arm of a large boomerang, and look like something made of wood when displayed for sale. *Katsuwobushi* is in great demand in Japan; it is grated and used to flavor soups, gravies, sauces, and various dishes.

The methods used by the Japanese in catching bonito and tuna in the tropical Pacific do not differ in any essential from those used by the tuna fishermen on the coast of California, except that their boats are not so modern and are not equipped with tanks for carrying successfully large quantities of live bait for long distances. In Japanese coastal waters they use drift nets a good deal, and also place great dependence on the use of long lines.

Almost nothing is known of the breeding habits of most of the commercial fishes of the tuna group that are canned as tuna. The spawning is probably pelagic. It is my belief that extensive breeding grounds for yellowfin and oceanic bonito exist in the Sea of Celebes and in that great section of the Pacific which lies east of Mindanao and north of New Guinea, forming a center of breeding and distribution comparable to the one in the western Pacific. Tuna and bonita occur throughout the year in Philippine, Bornean, and other East Indian waters, and the bluefin tuna also occurs off the Japanese coast all through the year. Extensive migrations also occur of those that form schools. In the Philippines they seem to approach from the south and east and gradually make their way northward; some follow the Pacific coast line, and others make their way through the Islands northward and northwestward, finally emerging into the China Sea. Eventually vast numbers make their way to Formosan and Japanese waters.

As these fishes pay no attention to man's puny political boundaries, some form of international commission should be organized to study their spawning range, local distribution, abundance, extent of migration, rate of growth, and other important matters connected with their life history. When this information is secured, international regulations could be devised to ensure the perpetuity of the tuna fisheries and make certain that this great natural resource is not blindly destroyed. This commission should be composed of scientific men only, representing Japan, the Philippines, the British and Dutch governments, and the United States also, so long as it is responsible for the welfare of the Philippines.

Included with the tunas are the Spanish mackerel, seers, or kingfish, and the petos or kingfish, all large to very large fishes that in the main are of excellent food quality. *Scomberomorus commerson,* or Commerson's Spanish mackerel or kingfish, rarely occurs as far north as Japan, but is common from Formosa southward in the Pacific and on into the Indian Ocean, ranging to Fiji, Australia, the Red Sea, and the east coast of Africa. It is an important and highly valued food fish wherever found. It is caught in quantity in the Philippines and East Indies by trolling, and about Formosa is taken by trolling and by nets. *Scomberomorus niphonius*, the Japanese seer, occurs in the coastal waters of Japan, Korea, and northern China, while *S. koreanus*, the Korean seer, has a still more restricted range, apparently being confined to the west and south coasts of Korea. *Scomberomorus chinensis,* the Chinese seer, occurs along the whole coast of China and north to the Japan Sea; it is abundant on the Korean coast. *Scomberomorus guttatus*, the spotted seer, is common on the China coast and around Formosa; it is also in the Philippines and ranges south to New Zealand and west to India. The Japanese, Korean, and Chinese seer-fishes thus have a restricted range, but Commerson's and the spotted seers have a very wide range. They are common in the clear tropical waters of ocean currents, around rocky isles, in tide rips, and offshore currents. Commerson's kingfish occurs in large schools, apparently of greater extent than those of the spotted kingfish.

The gigantic petos or kingfish, which are said to reach lengths of 8 to 12 feet, are more or less solitary pelagic fishes which do not school. They live well offshore, especially in the clear, highly saline, waters of ocean currents such as the Kuro Siwo. *Acanthocybium solandri,* Solander's kingfish, is found as far north as Tokyo Bay and the south coast of Korea, but occurs more often from the Bonin Islands southward and eastward throughout the tropical Pacific, and also in the tropical Atlantic and Indian oceans. Jordan and Hubbs have separated those found in Japanese coastal waters as *Acanthocybium sara.* If their distinction is valid, being based on the teeth, we have two species in the western Pacific, one from Japan and Korea, the other south of Japan proper. It is possible that different stages of growth and old age may make profound differences in the teeth, and further study is necessary to clear this point. *Grammatorcynus bicarinatus,* the two-lined kingfish, is found from the Philippines southward and west to the Red Sea. It is too uncommon to be of any commercial importance.

The *Gempylidae* or snake-mackerels are modified for a life at a considerable distance below the surface, so that they are more or less abyssal fishes. Several kinds of snake-mackerel are known from the western Pacific and are of general distribution; two of them are of economic importance in some parts of the world. Both are found from Japan and the Philippines throughout the warmer parts of the Pacific, Indian, and Atlantic oceans, at depths of a few hundred feet to over half a mile, usually from 100 to 400 fathoms. *Prometheichthys prometheus,* the rabbit fish, is abundant about Leyte and Hawaii. *Ruvettus pretiosus,* the castor oil fish, is the object of a highly specialized fishery throughout Melanesia and Polynesia; it is taken in Japan, off the coast of Luzon, and in the East Indies as well as at Hawaii. It is found also in the Atlantic, Mediterranean, and in fact all tropical and subtropical seas.

The *Trichiuridae* are most closely related to *Scomber* and are mackerels with the tail drawn out to a fine elongate point, as indicated by the common name of hair-tail. They are highly carnivorous, with huge teeth. At least three, if not four species occur in the western Pacific. One of them, *Trichiurus japonicus*, the Japanese hair-tail, occurs from Japan southward along the Chinese coast, and through the Riu Kiu Islands to Formosa and the northern coast of Luzon, as far as the Gulf of Lingayen, if not farther south. It reaches a length of two meters and is a very important food fish of good quality. The other species are East Indian, ranging north through the Philippines to the coast of China, and one to the south of Japan. The Japanese hair-tail and one of the more southern species, *Trichiurus haumela,* are caught in enormous quantities on the China coast and in southern Japan, the last-named species being almost as important commercially as the larger Japanese hair-tail.

The sail-fishes, spear-fishes, and swordfish are, as almost everyone knows, giant mackerels of the open sea that range immense distances. The swordfish is found in all warm and temperate seas and occurs all over the western Pacific wherever schools of sardines, mackerel, bonito, skipjacks, and other lesser fry abound. Throughout the entire Pacific it is taken wherever possible, but is not ordinarily sought for in particular. The native fishermen of Pitogo, on the island of Jolo, largest of the Sulu Archipelago, go out in season to catch swordfish from their vintas, but elsewhere except in Japan they are taken as a rule incidentally to the bonito and tuna fishery. Large numbers are caught by Japanese fishermen around the Bonin Islands and Riu Kiu Islands, and taken to the Tokyo market.

I can recognize but one species of sail-fish in the western Pacific, though some have tried to separate two species. The Oriental sail-fish is common throughout the entire region north of New Guinea and westward to the Philippines. In many places it is sought by native fishermen who go out in their canoes to harpoon it, a task not free from danger. Like the swordfish, the sail-fish follows the migrating hordes of lesser fish. Thus during April–May it is taken in the Gulf of Leyte in the Philippines; a month later it appears off the coast of Samar and the southeastern end of Luzon; by the end of June and in July it is taken on the Tayabas coast far up the eastern shore of Luzon. At the same time, swordfish, sail-fish, and spear-fish are taken to a limited extent at all times of the year throughout the central and southern Philippines.

There are said to be two species of marlin or spear-fish in western Pacific waters, though the few I have critically examined have all been *Makaira mitsukurii,* the striped marlin or spear-fish. It is caught in comparatively large numbers in southern Japanese waters and the islands southward such as the Riu Kiu and Bonin islands, and occurs everywhere southward in the islands north of the equator. Probably the black marlin also occurs in the western Pacific, northward to Japan. The striped marlin occurs all over the Pacific, at least north of the equator, and is taken commercially in Hawaiian waters and on the coast of California.

THE DISTRIBUTION OF THE MORE IMPORTANT MARINE MAMMALS OF THE PACIFIC OCEAN, AS IT AFFECTS THEIR CONSERVATION

By Robert T. Orr

Marine mammals, like fishes, constitute a valuable natural resource which is of some importance to most of the nations of the world. Among marine mammals by far the most valuable group commercially are the whales. Before discussing the distribution of the more important species in the Pacific Ocean it seems advisable to give a brief history of whaling and whaling legislation.

Whaling has been carried on for many centuries. We read in Greek literature of the capture of whales some 3000 years ago. In the tenth century Norway, France, and Spain carried on considerable whaling. It is, however, only in the last several centuries that whaling has been a productive source of income for many countries. Methods in this field of human activity, as in many others, have changed over the course of years, becoming more efficient and at the same time more deadly. In olden days sailing vessels were employed and whales were taken with hand-thrown harpoons from small open boats. The whales killed were the slower species that could readily be captured by such methods and were of necessity those that rarely sank when dead. These included principally the sperm whale (*Physeter catadon*), the northern and southern right whale (*Eubalaena sieboldii* and *E. australis*), the bowhead whale (*Balaena mysticetus*), and the humpback (*Megaptera nodosa*). Some of these species are now extremely reduced in numbers, even to the point of being rarities. The nineteenth-century whaler did not take fast-swimming species or those which sank upon being killed, such as the blue whale (*Sibbaldus musculus*) and finback whale (*Balaenoptera physalus*), as he was unable to surmount the difficulties entailed in their capture.

Modern methods are very much more destructive than those of the early days. Large steamboats are employed in hunting, each being equipped with small cannons which fire harpoons. After capture the whales are floated and towed to stations on shore or to large cruising factory steamers equipped to haul whales on board. According to C. H. Townsend (Zoölogical, Vol. 19, p. 5), about 40 factory steamers and a small number of shore stations are sufficient for the enormous annual catch of today. These floating factory ships have a displacement of as much as 30,000 tons and some are capable of storing 6,000,000 gallons of oil. The larger vessels are capable of handling as many as 15 large whales a day. Radcliffe (Jour. Mamm., Vol. 13, 1932, p. 251) records one whaler which reputedly took 1,350,000 gallons of oil in thirteen days. In the 1930–31 season 42,874 whales were taken. At the peak of the whaling period in the last century there were hundreds of whaling boats. In 1846 there were 735 whaling vessels sailing under the United States flag alone. It appears likely from statistics available that less than 10,000 whales were captured annually in those days. In fact in the 1919–20 season only 11,369 whales were taken in the world, or about one-fourth the total catch of the 1930–31 season.

In 1919 the Pacific Coast of North America supplied approximately one-tenth of the total world output of whale oil and has continued to supply nearly the same quantity of oil up to fairly recently. However, with the great increase in Antarctic whaling the percentage of the total world production of whale oil by the Pacific Coast has greatly decreased. In 1929 it only produced about one-fortieth of the total world output. The species taken were principally blue whales, finbacks, humpbacks, and sperm whales. In the

1930–31 season 29,410 blue whales alone were taken in Antarctic waters, a few Sei whales and a number of other species being taken in small numbers.

Thus it is evident that whaling has steadily increased and, as is true of most natural resources, it is only in recent years that attempts have been made at conservation.

In the United States, in 1928, the American Society of Mammalogists passed a resolution at its tenth annual meeting recommending "that steps be taken looking to the appointment of an international commission to investigate conditions and facts regarding the life history, habits, and commercial utilization of whales, and to make recommendations to the governments concerned as to procedure or regulations which will safeguard and perpetuate this resource for the benefit of all parties interested."

After a preliminary investigation had been made it was deemed most advisable to form an American Committee to work in close coöperation with similar organizations of foreign countries. At this time the British government had completed several years' investigation on the status of whales and whaling in the southern seas through expeditions sent out on the Royal Research ship *Discovery*. Likewise, in Europe at this time the Economic Committee of the League of Nations had been instructed to study the question of the protection of marine fauna and upon expert advice decide "whether and in what terms, for what species and in what areas, international protection of marine fauna could be established." "In July, 1929, the Economic Committee came to the conclusion that international measures might be contemplated to insure the protection of whales and that such measures were actually urgent."

In America, therefore, a Council for the Conservation of Whales was formed. Shortly afterward it recommended the following reforms as highly desirable:

"Immediate and absolute protection of such species of whales as are in serious danger of extermination.

"Protection of whales on certain rather circumscribed areas which they now use as breeding grounds.

"Protection of females nursing young.

"Compulsory utilization by whalers of the entire carcass.

"Prohibition of whaling in certain tropical areas where the animals are almost invariably too thin to be profitable.

"Prohibition of the use of aeroplanes for whale hunting.

"Establishment of an international committee; to operate a system for the licensing of the pelagic whaler; to secure coöperation of individual nations in licensing shore whaling stations, and in supervising their activities; and to make proper investigations and secure data on the conditions of whales."

On June 25, 1929, Norway, which until very recently carried on about four-fifths of the world's whaling, passed one of the best whaling laws in effect up to that time. It prohibited the capture of right whales, cows of any species accompanied by calves, and calves accompanying cows. The prohibition of whaling in tropical and subtropical waters, within certain prescribed limits, was left to the discretion of the king. Further regulations were affected regarding the fuller utilization of the carcasses by floating factories. A tax was placed upon whaling products, to be used in defrayment of expenses incurred in enforcing the law and to be applied to cetacean research.

Meanwhile, upon the recommendation of the Economic Committee of the League of Nations, action was being taken and on April 3, 1930, a Committee of Experts met in Berlin to consider possibilities for the international protection of marine fauna. The United States was represented by Dr. Remington

Kellogg of the National Museum. A preliminary draft of a convention was drawn up and submitted to member and nonmember states of the League for suggestions and consideration. In September, 1931, the Conference on the Regulation of Whaling which met in Geneva unanimously adopted a draft convention for the regulation of whaling. It was decided to open this Convention immediately for signatures.

The Convention applied only to whalebone whales and prohibited the killing of right whales, calves, or immature whales of any species or cows accompanied by calves. It contained provisions essentially like those passed by the Norwegian government in 1929. The Convention demanded that the fullest possible use be made of the carcasses. It also urged that gunners and crews be paid on the basis of such factors as species, value, size, and yield of oil instead of on the basis of number of whales taken. It required the licensing of whaling vessels and the collecting of scientific data, including locality of capture, species, sex, length, and certain other pertinent information. These data were to be kept by the International Bureau for Whaling Statistics founded at Oslo in 1930 upon the recommendation of the Whaling Committee of the International Council for the Study of the Sea. The Convention was to become effective subject to the ratification of eight countries including Great Britain and Norway. It was not, however, until January 16, 1935, that the Convention became operative, the delay being attributable to the difficulties incident to ratification by many nations.

On June 8, 1937, an International Conference on the Whaling Industry was concluded in London. It was here agreed, subject of course to ratification, that there should be an annual closed season of nine months for pelagic whaling, and of six months for shore stations; that the killing of baleen whales be prohibited between 40° S lat. and 20° or 35° N lat. (varying with the long.); that right and gray whales shall be protected at all times, and full protection be given blue whales of less than 70 feet, fin whales of less than 55 feet, and humpback and sperm whales of less than 35 feet in length. Representatives of nine nations including Norway, Great Britain, and Germany signed this agreement, and the United States Senate assented to its ratification on August 5, 1937.

A second International Whaling Conference was held in June, 1938, at which delegates from 13 countries, including United States, Great Britain, Norway, Germany, and Japan attended. Additional provisions agreed to include the protection in Antarctic waters of humpback whales for a period of one year, establishment of a baleen whale sanctuary in the Antarctic Ocean between Graham's Land and the Ross Sea, and the prohibition of pelagic whaling in the Arctic Ocean.

This briefly outlines some of the more important developments connected with the history of whaling and legislation now in effect to conserve these valuable marine mammals. Our next problem deals with the distribution of whales. These data have been compiled by various students of the cetacea largely from the records, both present and past, of various whaling vessels.

Most of the larger species of whales which are now used commercially are circumpolar in distribution, hence data regarding their latitudinal limits are in a rather general way applicable to the species in all oceans in which they occur. Ocean currents do, however, modify their distributional limits in many areas.

The following species of whales are, or have been, of importance commercially in the Pacific Ocean: the sperm whale, the northern and southern right whales, the bowhead whale, the blue whale, the finback whale, the Sei whale, the humpback whale, and the California gray whale.

The sperm whale (*Physeter catadon*) is not at present a very important constituent of the world catch of whales, although in a few areas it does form a rather large part of the catch. Owing to its habits, however, it offers a most suitable subject for commercial use, providing certain rules are adhered to. The species is limited pretty much to tropic and temperate regions, migrating to the latter to some extent during the summer months. It is during this migration, either to the northward or to the southward, that pairing takes place and the females give birth to young in subtropical or temperate waters. A certain proportion of the sexually active males, however, leave the females at the height of the pairing season and migrate alone to high altitudes. These same individuals return later to temperate waters and join the schools in their migration to wintering areas on the equator.

Since the species is polygamous and the sex ratio is about even, so far as known, and as only a percentage of the adult males and no females indulge in these far northward and southward migrations during the summer seasons, it would appear that even unrestricted capture of sperm whales north and south of latitudes 40° N and 40° S, respectively, would not likely have an adverse effect upon the world stock of this species. This is assuming, of course, if complete protection were afforded to all within these latitudes. This, however, would be somewhat adverse to Japanese whaling interest and only of some slight value to whaling in the New Zealand area.

There are probably at least two species of right whales; possibly more, but this has yet to be proved or disproved. At present it is generally accepted that the northern right whale (*Eubalena sieboldii*) and the southern right whale (*Eubalena australis*) are specifically distinct. If they are not, this presents a remarkable instance of discontinuous distribution, as the right whales are strictly inhabitants of the colder waters in each hemisphere, the northern and southern forms being separated from each other by vast expanses of tropical and temperate waters. According to Townsend (1935), as far as right whales are concerned in the Pacific, the region between 30° N and 30° S lat. represents a vacant tropical belt in which there are no records in the logs of the 1670 whaling voyages that he examined. In fact in the North Pacific most of the range of the right whale lies north of 40° N lat. Most of the whaling was from the Sea of Japan northward and eastward to the Bering Sea. At present both the northern and southern right whales are very much reduced in number and are given rigid international protection.

The bowhead whale(*Balaena mysticetus*), or great polar whale, as it is sometimes called, is another species now greatly reduced in numbers. It was highly sought after in early days because of the large amount of oil it yielded. As much as 265 barrels are recorded as obtained from single individuals of this species.

The bowhead whale is circumpolar, occurring in the North Pacific from about 53° N lat. north and from the Okhotsk Sea to the vicinity of the Pribilof Islands in the Bering Sea. Northward its range extends into the Arctic Ocean from Wrangel Island on the Siberian coast east to the Amundsen Gulf. The southern extent of the range of the species is marked roughly by the southern extent of the ice barrier in winter. Seasonal movements of course take place and as the ice breaks up in the spring the bowheads move farther northward.

The blue whale (*Sibbaldus musculus*) is the largest and swiftest of the rorquals, exceeding the finback and Sei whale considerably in size. It is, in fact, the largest animal living or known to have lived on this earth. Large individuals sometimes reach well over 90 feet, the record being 98 feet for a specimen taken at Panama (S. F. Harmer, Proc. Zoöl. Soc. London, 1923, pp. 1085–1089). As a result of its size and wide distribution the species has been eagerly sought after ever since the introduction of power boats and the harpoon gun.

Blue whales are widely distributed over the arctic, temperate, and antarctic waters. In the Pacific the species is common along the coast of South America and at times even along the Lower California Coast, although many individuals have been taken much farther north along the American coast. On the Asiatic side the species is regularly taken by the whalers of Japan and Korea.

While this species is now one of the most important economically, the annual toll is so enormous that serious depletion has already occurred in the world stock of this species.

The finback whale (*Balaenoptera physalus*) is exceeded only by the blue whale in size and speed. The average yield of oil from a fin whale is 35 to 50 barrels as compared with 70 to 80 barrels for a blue whale. Exceptionally large individuals sometimes measure slightly in excess of 80 feet. Like the blue whale the finback is a swift-swimming species and for this reason has survived the attacks of the old-time whalers. It is now, however, relentlessly pursued and with the blue whale constitutes the bulk of the world's catch today.

The distribution of the finback whale is quite similar to that of the blue whale, although it is somewhat less common in Antarctic waters than the latter. It is common off the coast of South America, but in the Pacific, off the west coast of North America, it is relatively rare. The species is again reported to occur in considerable numbers off Japan, Korea, and the Kamchatka Peninsula. In the Atlantic Ocean it is the predominant species.

The Sei whale (*Balaenoptera borealis*) is the smallest of the three commercially valuable rorquals that occur in the Pacific Ocean. It forms a very small percentage of the catch in most whaling areas except off Japan, Korea, and the west coast of Norway. The species, therefore, has suffered little from commercial whaling. The reason for this is its small size and consequent small yield of oil. One blue whale will yield as much oil as six Sei whales. When the larger species become critically reduced in numbers, a condition that may easily occur, undoubtedly smaller forms such as the Sei whale will then suffer. Like most of the commercially valuable species of this group the Sei whale migrates to the north and south of the equator, depending upon season, and breeds in subtropical waters. It does not come as close to the poles, however, as either the blue or finback whales.

The humpback whale (*Megaptera nodosa*) is a slow-moving, coastwise species of whale the distribution of which is roughly similar to that of the sperm whale. They breed in tropical or subtropical waters and then migrate to the north and south, depending upon season. Humpback whales are taken in the Northern Hemisphere between 40° N and 10° N, generally from October to March. In the Southern Hemisphere they are taken between 40° S and 10° S from June to September. Unlike many species of whales, they seem to follow very definite migration routes and apparently are not distributed over the ocean at large. Owing to the sluggish habits of the humpbacks and their coastal predilections, they are generally the first species to suffer when new whaling areas are opened up or discovered.

The California gray whale (*Rhachianectes glaucus*) is another species that was formerly quite abundant but is now very scarce as a result of intensive hunting in the early days. The species, according to Captain Scammon, formerly occurred in numbers from the California coast south to about 20° N lat. between November and May. During this season it very often frequented the quiet shallow lagoons where the young were born. It was here, however, when they were congregated that California gray whales were slaughtered in large numbers by the whalers. Whaling for this species also was carried on along the coast close to shore during spring and fall periods of migration, when the gray whales were moving in large herds in or close to the kelp beds. During the summer months gray whales move north into the Arctic Ocean and the Okhotsk Sea. It can be seen, therefore, that the species from the nature of its habits of staying close to the coast and bearing its young in bays had little chance of maintaining itself in any numbers.

In conclusion it may be said that while commercial whaling has been carried on for over a century on a relatively large scale, it is really only about a decade ago that practical measures were taken toward the conservation of the sources of revenue for this industry. The general attitude has been that the oceans are large and it would be impossible to exterminate any species inhabiting them. Whether this be true or not, it would certainly appear that certain whales, such as the right and bowhead, which have not figured in commercial whaling for years, have not come back. When a species approaches the verge of extinction, many factors, some of which man is probably unaware of, may prove detrimental to its survival. It would be well, therefore, for us to profit by experience and make every attempt possible to conserve, for profitable use, those species the numbers of which have not as yet been so reduced. Protection such as the United States, Great Britain, Russia, and Japan have given to the Alaska fur seal has proved extremely profitable to all concerned. Since an international treaty was signed by these countries on July 7, 1911, the fur seal herd has increased from 125,000 to 1,839,119 according to the 1937 estimate. Each year a number of the bachelor seals are killed, without injury to the herd as a whole, and the profits from the skins are divided among the various countries concerned. In 1937, 55,180 seal skins were taken. Let us hope, then, that so efficient and profitable a type of conservation may be carried out for the cetacean population of the world and the industries dependent upon this population.

THE SEA OTTER, PAST AND PRESENT

By Edna M. Fisher

The sea otter is the rarest as well as the most valuable of all the fur-bearing mammals ever known. The rich quality of the fur was well known to the peoples within the otter's range of distribution for hundreds of years before the Europeans started the mad rush of intensive and indiscriminate hunting.

The adult otter is approximately 4 to 5 feet long and streamlined. The otter has two pairs of legs, the anterior pair being short and strong and ending in small paws, and the posterior pair long and powerful and terminating in elongated and webbed toes. The hind feet are almost completely covered with fur on both surfaces, and the paws have a naked black skin on the palmar surface. The tail is furred, flattened, and almost if not equally as long as the posterior legs when extended backward.

The sea otter spends most if not all of its life in the water and most of this time floating and swimming on its back. The sea otter female has only one pup at a time, rarely two, and she does not produce a young one every year. This slow rate of reproduction is important to remember when studying the fur trade as related to the sea otter.

The normal range of the animal was and still is from the northern islands of Japan northward and eastward along the coast and then along the Aleutian Islands to the Alaskan coast. From the coast of Alaska they were to be found along the coast and among the islands of British Columbia, Washington, Oregon, California, and Lower California. The present distribution has not extended beyond the limits of the former range.

The various Indian tribes that lived along the coasts on the islands within the otter's range hunted the animals for their fur, which was used for clothing for the women and children and for covers for their beds. Seldom did they use the flesh of the otter for food, and still more rarely did they fashion artifacts from its bones. One rather interesting use was in the making of fire by the process of striking two flints together and letting the sparks fall on some sea otter fur mixed with sulphur (Coxe, p. 171). Kotzebue (Vol. 2, p. 60) relates how "One [Indian] only stood a little apart; he was particularly decorated with ermine-skins and feathers, and beat time for the dancing with a staff ornamented with the teeth of the sea-otter."

Japan and the Sea Otter

Sea otter furs were used by the Japanese nobles and feudal lords for several hundred years before the commercial exploitation started. Owing to the feudal system, few furs were taken to supply the needs and demands of the relatively small number of nobles.

During the period of rapid expansion by Russia and the more rapid depletion of the sea otter the Japanese were at first ignorant of what was taking place and then realized their lost chances with great alarm. The Japanese could not prevent the Russians, nor later the Americans, from killing the sea otters around their own islands, practically at their very door. And what was equally as bad from their point of view was that they were unable to compete with either the Russians or the Americans to gain a share of the rich harvest of furs.

Japan, like Spanish California, made numerous laws for the control of the sea otter fur trade within its own waters, but, also like them, was unable to enforce any laws on the water. In 1884 the Minister of Agriculture and Commerce published a decree for the protection of the fur seals and sea otters on the island of Hokkaidô. Hunting was strictly prohibited, with payment of heavy fines if any violator was convicted. On the other hand, the Minister might grant to whomever he pleased special permits to hunt within this area (Hokkaidô), for any sum that he might care to charge. Of course the hunter was to turn in to the proper officers reports to cover all furs taken under such a permit. In 1886 an imperial decree was published for the further regulation of fur seal and sea otter hunting and the importation of similar furs taken within the boundaries of either Russia or the United States. These regulations were made in all seriousness, but were never enforced up to 1895, when new laws were enacted. The new laws were more exacting in the matter of detailed reports than those of earlier years, but as before, the hunter could obtain a license without too much trouble. The hunter could then go happily on to catch his fur seals and sea otter as long as he observed certain routines and red tape in the making out of the lengthy reports. In 1897 the government passed laws to provide subsidies for ships engaging in the fur trade, thus paying men to hunt fur seals and sea otter, offering all encouragement and no very great discouragement.

In 1887 the United States became very much interested in the protection of the fur seals within the Alaskan waters, but ignored the sea otters. Representatives of the Japanese government approached officials of the United States government on the subject of the protection of the sea otter as well as the fur seal, but for some reason the United States government was not interested in saving the sea otter. The idea of an international agreement to protect these two valuable fur-bearers was nevertheless started and it made a deep appeal to many interested persons in the different countries. But after numerous meetings and much talk the subject was dropped for the time being. Several years later, the subject of protection again became of interest to all of the countries concerned, and in 1911 the agreement was signed by the United States, Great Britain, Russia, and Japan.

At present, Japan sends one to three patrol boats north to cruise around the islands frequented by sea otters to make sure that no unauthorized persons visit these islands, and to visit the various government stations that are maintained on them. According to Bergman (p. 181), the largest supply is to be found around Onnekotan, Harimokotan, and Shiachkotan. He also states (p. 182) that the Agricultural Department catches each year only fifteen sea otters. The government employs an expert hunter who spends about forty days in June and July getting these fifteen otters. The hunter is assisted by a few other men from the island stations who help in setting the large nets (3 nets each about 12 feet wide and 300 feet long) on foggy days when the water is calm. Bergman also reports that the number of otters is gradually increasing among the Kuriles under the ever watchful eye of the Japanese government.

RUSSIAN EXPANSION AND THE FUR TRADE

The Russian explorers and adventurers had reached the Pacific Ocean on the shore of Kamtchatka by 1706. They ruled over most of the Siberian peoples with whom they had come in contact, and were ready to explore farther. The natives living along the coast reported rich lands over the water to the east and the tales they told furnished the incentive needed to cause the Russians to start a new eastward push. The government became interested and helped to organize several new expeditions for further explorations into the great unknown.

Vitus Bering was the first to be sent by the Czar to seek the new lands. Bering sailed eastward in 1727, exploring as he went the new islands that he found, and after much suffering and many severe hardships he made his way back to St. Petersburg (now Leningrad) and reported his findings to the Czar. Bering strongly recommended that future voyages be made to establish trade routes not only to Japan but to this new country (America) as well.

In 1740 Bering started with two ships from Kamtchatka on another voyage to the east. On this trip he sighted the mainland of America although he never landed on it. On this his last voyage he secured, among other things, the skins of some 700 sea otters, which were brought to Kamtchatka in 1742. Bering died on the return voyage. The skins brought back from this voyage gave the necessary impetus that started the rapid destruction of the "sea beaver," as the Russians called the sea otter.

Russian expansion in the Pacific was slow at first, but increased more rapidly as Kamtchatka developed as a port and base of supplies. The demands and prices offered by the Chinese fur markets were added stimuli to the hunting of the sea otter. Private individuals as well as trading companies, encouraged by the government, outfitted ships for exploring new lands and, most important of all, for securing the skins of the valuable sea otter. A ship was usually out from Kamtchatka for a two-year period; rarely did they return within a year. The winter was spent on some island where their collecting activities were continued as the weather permitted.

Usually a captain and boat made only one trip and then the merchant who was financing the trip withdrew, quite often because the returns on the small number of furs brought back as the merchant's share were far below the cost of the trip and the merchant was bankrupt. Several captains made two voyages eastward, and a few made three or more hunting trips. Andrew Tolstyk was one of the most successful of these early explorers, making at least three trips (1749, 1756, 1760), on which he collected 9397 adults and 821 cubs, a total of 10,218 sea otters. The crew of each ship was trained to capture, kill, and skin the otters, and it was not until some time later that natives, mainly Aleuts, were employed as hunters.

From the very beginning the hunters killed all adult otters they could find and even took the cubs. A cub is a young otter six months or more in age when it has lost the "woolly" hair and has that characteristic of an adult. The helpless pups were left to sink or swim and surely to starve, for the greed for skins was such that the hunters saw only the immediate demands and big prices and thought nothing of the future. The Russians repeated their visits to the various islands almost every trip to be sure that they had caught every otter possible in that area, and when there were no more otter they were forced to seek new hunting grounds farther to the east. This progressive extermination was carried on by all the sea otter hunters across the Aleutian chain of islands to the American mainland. An eastern base for supplies was first established on Kodiak Island in 1781 (Russian American, p. 44; New York Herald, April 29, 1867) and at Sitka in 1804 (Kotzebue, 2, p. 37). After the establishment of the mainland base the Russians employed larger numbers of Aleut hunters than they did Russian. It was not only less expensive, but the Aleuts were skilled in otter hunting and had the necessary equipment.

When the Alaskan waters had been so thoroughly combed that few sea otter remained thereabouts, the Russians, under the supervision of the Russian American Company, extended their hunting gradually southward along the American coast. With the decrease in the number of otters the hunters were forced to go so far to the south that they found it necessary to build another base of operations nearer to the supply of otters. As a result of this need Fort Ross in Marin County, California, was established in 1812, then a post at Bodega, and a little later an important hunting station on the Farallones. From Fort Ross the boats hunted ever southward, relentless in their pursuit of the sea otters. Each boat was equipped with several Aleuts and their canoes, or bidarkas, which were brought from their homes in Alaska for this work.

In California waters and to some extent in the Alaskan waters they found the English and the Americans very active competitors. The English activity was short lived but that of the Americans was continuous and energetic. The Russians as well as the Americans found it to their own advantage to enter into a contract for the hunting of sea otters. This contract system lasted for only a short time. Likewise the Russians joined in a contract with the Spanish government after that with the Americans was discontinued, and this system might be called the "share system," for each party to the contract was to share equally in the catch. Finally there were no otters left to hunt and the Russian expansion ceased and the withdrawal began. In 1841 Fort Ross was sold to Captain John A. Sutter for 42,857 roubles and 14 copecks silver (Russian American, p. 111, Lieutenant Captain Golovin, Survey of Russian Colonies in North America).

For some reason the Russians could not sell their furs directly in the Chinese markets, but instead the furs were always shipped to Kiachta on the China-Siberian frontier, where they were able to dispose of all furs at enormous profits. Russia even bought sea otter furs from England which were sold on the Siberian frontier. At least 22,932 skins were shipped from England to Russia between 1775 and 1777. Most of these skins had been collected by the Hudson Bay Company and various Canadian trappers.

English Hunters

In 1776 Captain James Cook left England on his third voyage into the Pacific. This famous voyage to the northwest coast was partly for exploration and partly for the collection of furs. The report of this voyage was published by the English government in 1784 and the very next year found ships of all nations sailing for the North Pacific in search of the sea otter and the wealth that was theirs for the taking.

Suddenly it seemed as if almost overnight the Americans, English, French, and Portuguese became fired with enthusiasm and hopes as great numbers set sail for this relatively unknown region. Even the Spanish government became conscious of the presence and the value of the sea otter. Nor did the Russian interest lag far behind the others.

Several English vessels visited the northwest coast following the publication of the report of Captain Cook's third voyage. Captain George Dixon in the ship *Queen Charlotte* and Captain Portlock in the *King George* made a trip around the world between 1785 and 1788 and did not neglect to visit the northwest Pacific, where they collected at least 2552 sea otter skins. These skins were sold at Canton for a fair sum, though Dixon thought the price much too low (Dixon, 1789, p. 321).

Captain Hanna visited the northwest coast in 1785 in search of furs. He got approximately 560 skins, which he sold at Canton in 1786. He had 500 whole skins of five different grades, the best priced at $60 and the poorest at $10. He had 240 flips and odd pieces which were valued much below the whole skins. The smallest scrap, no matter how worn or dirty, was bought by the Europeans, and these found a sale in Canton. The 240 pieces were estimated as equal to 60 whole skins with a value of $60 each. This cargo paid $20,600 to the company that sent out the ship and the owners felt it worth while to try again. In 1786 Captain Hanna again sailed from Macao in the *Sea-Otter* for the American coast. This voyage was not as rich in returns as the previous one and the ship returned to Macao in 1787 with only 100 whole skins valued at $50 each and 300 pieces of an inferior grade. The cargo brought only $8000 to the merchants.

In 1786 two ships set sail from Bombay for the North Pacific area to engage in the fur trade. They were the *Captain Cook*, Captain Lorie, and the *Experi-*

ment, Captain Guise. The cargoes of these two ships consisted of approximately 604 skins of various qualities and were sold at Canton in 1787 for $24,000.

Captain John Meares in the *Nootka* sailed from Bengal in 1786 in search of furs. He was rather successful, getting 50 sea otter skins that brought $91 each, an unusually high price at this time. He got besides these 267 whole skins of all grades ranging in price from $70 for the best to $5 for the very poorest grade.

Captain Berkley in the *Imperial Eagle* visited the American coast at about the same time as Captain Meares and collected some 800 skins, most of which were of a superior quality. The cargo was valued at $30,000 at Canton.

A few more English ships visited the North Pacific in search of furs before conflicting privileges and laws stopped them. The first handicap to the English was that the exclusive right to trade with China was held by the East India Company. This was the same as closing all Chinese markets to all English ships not belonging to this company. The rival company was the South Seas Companies, the ships of which were well suited to engage in the fur trade but could not enter Chinese ports. This company in turn attempted to prevent its rival from crossing the Pacific to engage in the fur trade. Competition was to the disadvantage of each company in that other nations' ships were free to trade anywhere (Cleland, History of California, p. 6).

In October, 1790 (Bancroft, California Pastoral, p. 460), Great Britain and Spain entered into a treaty which prevented any English subject from hunting sea otter within 30 miles of any part of the American coast occupied by the Spanish. This meant all waters from San Francisco Bay south to the tip of Baja California, or as far south as there were sea otter. This treaty gave added advantages to the adventurous Americans who were appearing in greater numbers on the coast every year. So from 1790 on England has played a very minor rôle in the sea otter fur trade. Occasionally sea otter pelts are offered for sale in London, but these are usually skins that have been confiscated from some Indian or those from dead animals that have washed ashore. Live sea otters have been seen off the coast of British Columbia at rare intervals in recent times.

French Interests

The French, too, were interested in the Pacific northwest, assertedly in exploration but just possibly in the fur trade. They were at no time as active as the countries so far discussed but they did try to compete with them. And we find M. de la Peyrouse in the *Astrolabe* and De Langle in the *Boussale* sailing from France in 1785, the year after the publication of Cook's report of his third voyage. These two Frenchmen were in the Pacific from 1785 to 1788 and with all their exploring they managed to get some 1000 skins of the sea otter, which they took to Macao and tried to sell to the Portuguese. This sale was not completed and later the same skins were offered for sale at Canton, where they brought $10,000.

La Peyrouse blames the English for having sold so many furs in the Canton market that the price was far too low to please him. If France could only establish a factory on the American coast, then the French could market regularly large numbers of superior furs! This hope never materialized and France soon dropped out of the competition for furs. A few other French ships started for the California coast and the North Pacific, but they either did not get here or were unsuccessful traders so far as concerns the sea otter. And so France, a rival for the fur trade, lost out almost at the beginning. The interest of the French and the voyage of La Peyrouse nevertheless were a decided stimulus for increased efforts by the countries that were hunting sea otter in the region.

The Portuguese and the Fur Trade

Portugal, like the other European countries, became greatly interested in the fur trade after the publication of Cook's voyages. Although the Portuguese were intensely interested they did not take a very active part in the fur trade. A few ships were sent out at the time when the other countries were also sailing to the North Pacific. How successful they were I have not yet determined, but it seems to be fairly certain that their efforts were feeble as compared to some of their competitors.

Spanish Efforts

The Spanish Government in California had the best opportunity to realize the greatest profit from the thousands of sea otters that inhabited the coastal waters. At first the Spanish did not know the value of the furs, for they thought an otter skin worth no more than two rabbit skins. And after the Spanish did realize the value of the furs the hunting of sea otters was inhibited by numerous rules, laws, and regulations, all of which must come from Mexico City if not from Spain. Too many laws and too slow a means of communication were the first handicaps for the Spanish. The second difficulty lay in the fact that the Spaniards themselves were not skilled as hunters on water nor inclined to such a strenuous life as that required for the capture of the ever elusive sea otter. The Spanish Californians depended on the native Indians to catch the sea otters for them and these Indians were not only indolent and lazy, but lacked the requisite interest, skill, and technique for pursuing the otter. Hence the Spanish part in the sea otter fur trade was as nothing compared to the Russians and Americans.

A few thousand skins were collected by the Indians and deposited at the various missions during this period. These skins were collected by a government agent and taken to Acapulco on the west coast of Mexico and thence by Manilla galleon to the Orient and the Chinese market. In 1795 the governor of this region complained that it did not pay to collect skins since they could not buy Chinese goods in Canton, a monopoly held by the Philippine Company. When the government ceased to collect the furs the missions continued to accept them from the Indians and these skins the padres later traded with the English and American ships for supplies needed for their missions. This trading had to be carried on by the padres quietly because it was breaking one or more of the numerous laws relating to the fur trade.

Most of the Spanish effort was spent in correspondence, in making laws and numerous regulations to govern the fur trade and to try to keep the other nations from entering Spanish waters and taking the sea otter. Spanish California was virtually helpless to enforce these laws on the water at any place along the long coast line. As a result the foreign ships were stopping at any point they desired to collect skins and feared nothing from the Spanish. The Aleut hunters employed by the Russians and the Americans were able to enter San Francisco Bay and hunt sea otter openly and the Spanish were unable to stop them, owing to lack of boats. The Spanish finally posted groups of soldiers around all the springs and fresh-water streams, thus limiting the supply of drinking water of the invaders, and this did slow them up, but eventually they killed every sea otter to be found in the Bay. The Spanish Californians stood helplessly by while the more energetic and ambitious and better-equipped nations relieved them of one of their most valuable possessions.

In 1823 Luis Argüello, then Governor of California, thought to solve the great difficulty by entering into an agreement with the neighboring Russians. The Spanish were to permit the Russians to hunt sea otter in California waters (as if they didn't already) and the catch of furs was to be shared equally between the two countries. This share system worked well for the Russians but not for the Spanish; for example, in 1826 one take of 63 skins was divided so that the Russian half was 44 and Spanish half was 19 (Bancroft, History of California, Vol. 2, p. 651). The agreement was renewed for three years in succession and then in 1826 the share system was permanently discontinued.

Americans and the Sea Otter

Only the briefest résumé of the activities of the Americans can be given at this time. So many ships came to the Pacific Coast each year in search of furs that to recount their exploits would require more space than is allowed. The Americans equaled the Russians in importance in the ruthless pursuit of the sea otter. They possessed most of the advantages that made it possible for them to surpass all competitors in the wide Pacific. All their ships were sent by merchants or companies and were not government undertakings. The Americans were footloose and fancy free as regards all treaties and privileges, and the laws of Spanish California did not bother them in the least. Also they were hardy, courageous, seafaring men filled with great enthusiasm and determination and possessing a remarkable energy and ability for carrying out their plans. They took advantage of every opportunity to procure the desired pelts, sometimes getting caught by the Spaniards, but on the whole being decidedly successful.

The Russian catch of otters was on the decrease at the time of the arrival of the Americans. This might have been due to the decreasing price in Canton and the increasing scarcity of otters that dulled the enthusiasm that was so noticeable in the first Russian hunters. And again it might be due to the better equipment and superior organization of the American hunters. The Americans were able to get 6000 to 7000 skins in a year when the best the Russians seemed to do was 600 to 700 skins.

Between 1785 and 1803 at least 74,528 sea otter were taken and most of these by the Americans. Over 13,000 were taken along the coast of California. The average price was $25 or less per skin, although exceptionally fine ones might command a higher price. Most of the time, the sea otter skins from California were considered inferior in quality to those of the Alaskan area, although there are occasional statements that they were about equal in value.

From 1803 to 1816 numerous American captains entered into contracts with the Russian American Company. The Russian American Company was to furnish Aleuts and bidarkas for a certain sum. This was convenient for the American captains because they did not have to carry so much equipment on the long voyage to the Pacific and would have more room in the hold for a larger cargo of furs. The Americans fared better in their dealings with the Russians than the Spanish did later.

Under the contract system more than 25,452 sea otter were killed, most of them along the California coasts. The otter were pursued and killed from kelp bed to kelp bed and into all the coves, in fact anywhere that they might try to seek safety. Ever southward pushed the hunters until the number of otters decreased so greatly as to make it unprofitable to hunt them. The otter taken under the contract system no doubt went in part to the Russian American Company and are included in their total of 124,209 skins for the period of 1797 to 1861.

Some of the hunters were of the opinion that the decrease in the number of sea otters was due to the fact that the incessant hunting had caused them to seek places of safety unknown to any man of that day. No one realized fully that they were not moving away but were being exterminated rapidly throughout their entire range.

In 1867 the United States bought the Alaskan Territory from Russia and thus came into possession of most of the native habitat originally occupied by the northern sea otter. The United States Government was not especially interested in the sea otter, certainly not enough to see that they were fully protected. It is reported that in 1869 more than 5000 sea otter skins passed through the customs in San Francisco, and the Americans continued to take otter long after this. The Alaska Commercial Company of San Francisco imported at least 54,143 sea otter skins from Alaska in the 33 years between 1871 and 1904. The growing scarcity of furs in turn produced a raise in price and one superior sea otter fur sold in the London market in 1880 for $475.

From 1867 on there was a constant stream of letters and petitions to the various departments of government at Washington asking them to do something to protect the fur seal and by all means the sea otter. Captain Hooper was one of the most persistent in begging for the protection of the otter. He even worked out a code, which he submitted to the government. This code was not adopted at the time although many of the suggestions in it were most valuable. Finally, after several international conferences and much argument, an international agreement was signed in 1911 by the representatives of Great Britain, the United States, Russia, and Japan. This agreement is more often called the Fur Seal Treaty. It gives protection to three species of northern fur seal and the northern sea otter north of the 30th parallel. It does not protect these animals against the activities of citizens of other countries, nor does it protect them south of the 30th parallel outside of the three-mile limit. Each state or province in America bordering on the Pacific has supplemented this treaty with laws and regulations of its own. These state laws are carefully enforced by an active and alert group of men who are personally interested in conservation of wild life.

After organized hunting ceased, numerous individuals and small companies continued to hunt sea otter along the range of the animal until laws were passed for the complete protection of the sea otter and were enforced. At the present time rarely is an animal killed and then it is quite possibly an accident.

Table 1 is but a partial list of the number of sea otters taken. This material and more was gleaned from the literature dealing with the history of the Pacific coast, for which I am greatly indebted to the California Fish and Game Commission, the Bancroft Library of the University of California, and Dr. and Mrs. Charles Singer of London.

No effort has been made at the present time to make this in any way complete, and, as is to be expected, some of the figures given may be duplicated in others, although great care has been taken to avoid all data that seemed to be repeated several times and to include them only once.

TABLE 1

Numbers of Sea Otters Taken

Dates of voyages	Captain of ship	Skins taken			Total
		Adults	Cubs	Pieces	
1727	Vitus Bering	A few skins			
1740–1742	Vitus Bering	700 to 900			900?
1745–1747	Nerodtsikoff				320
1747–1749	Andrew Wsevidoff				1040
1747–1748	Feodor Cholodiloff	250	100		350
1749–1753	Nikiphor Trapesnikoff	1700	220		1920
1749–1752	Andrew Tolstyk	1709	119		1828
1750–1754	Emilian Yugoff	755	35		790
1750–1752	Andrew Wsevidoff	700	120		820
1753–1755	Feodor Cholodiloff	1600			1600
1753– ?	Serebranikoff				?
1754– ?	Ivan Krassilnikoff				103
1756– ?	Andrew Tolstyk	5030	330		5360
1757– ?	Ivan Skilkin	230	(all lost)		230
1759–1761	Andrew Serebranikoff	2350			2350
1760–1762	Betstrevin	800	100		900
1760– ?	Andrew Tolstyk	2658	372		3030
1762–1763	Nikiphor Trapesnikoff				20
1762– ?	Terenty Tsebaeffskoi and Co.				150
1765– ?	Orechoff, Lapin, Shiloff	570	30		600
1772– ?	Ivan Popoff	1100			1100
1775	Hudson's Bay Co., and others	7143			7143
1776	Hudson's Bay Co., and others	12086			12086
1776	Captain Cook	Several skins			
1785–1786	Captain George Dixon and Capt. Portlock				2552
1785	Captain Hanna	500		240 flips	560
1786	Captain Hanna	100		300 flips	110
1786–1787	Captain Guise and Captain Lorie	600			600
1786	Captain John Meares	348		66 flips	348
1786	Captain Berkley				800
1785	Spanish Government				1600
1787–1790	Spanish Government				9729
1787	Spanish Government				200
1788	Spanish Government				1500
1794	Russians				2000
1798	Russians				1200
1799	Russians				300
	Captain Rowan	2429	200	2141 t.	2629
	Captain Rowan				2800
	Captain Lamb				1200
	Captain Crocker				1700
	Captain Breck				1400
	Captain Duffin				1000
	Captain Beck				700
	Captain Cleveland				2200
1800	Captain Bowles				2400
	Captain Bowers				2200
	Captain Dodge				1200
	Captain Davidson				2000
	Captain Duffin				2000
1801	Captain Swift				3200
	Captain Ingersoll				1500
	Captain Bumstead				2000
	Captain Pierrepont				700

TABLE 1—(*Continued*)

Dates of voyages	Captain of ship	Skins taken			Total
		Adults	Cubs	Pieces	
1801 (*Cont'd*)	Captain Dorr				1300
	Captain Hubbell				600
	Captain Ockington				600
	Captain Holbrook				2000
	Captain Dorr				1500
	Captain Kelby				700
1802	Captain Cunningham				3500
	Captain Wild				3000
	Captain Derby				3000
	Captain Brice				300
	Captain Ebbetts				2000
	Captain Worth				1200
	Captain Crocker				500
	Captain Briggs				500
1803	Captain Bowles				500
1803–1804	Joseph O'Cain (Russian contract)				1100
1805–1806	Joseph O'Cain (Russian contract)				6250
1810–1811	Jonathan Winship (Russian contract)				5400
1810–1811	Nathan Winship (Russian contract)				1120
1812–1814	Russians (Various boats)				877
1813–1815	American boats with Russian contracts (*Isabella, Mercury, Catherine, Amethyst, Charon*)				10000
1811–1815	Juan E. de Castro				400
1815	Russians				153
1816	Russians				97
1817	Russians				55
1818	Russians				13
1819	Russians				71
1820	Russians				22
1821	Russians				35
1822–1823	Russians				43
1823–1824	Spanish-Russian share system				1500
1824	Russians				475
1825	Spanish-Russian share system				468
	Russians				500
	Russian ships *Okhotsk, Kiakhta, Baikal*				63
1826	Captain Cooper				375
	Russians				287
1827	Russians				12
1828	Russians				1
1829	Russians				23
1830	Russians				34
	Spanish				30
1831	Russians				112
1832	Russians				1
1833	Russians				221
1834	Russians				225
1797–1821	Russian American Co.	72894		34546 t.	72894
1821–1842	Russian American Co.	25416		23506	25416
1842–1861	Russian American Co.	25899		25797	25899
1869	Customs inspection at San Francisco reported				3000

TABLE 1—(*Continued*)

Dates of voyages	Captain of ship	Skins taken			Total
		Adults	Cubs	Pieces	
1870	Russians				11
1871	Russians				28
	Americans				609
1872	Russians				14
	Americans				3092
1873	Russians				22
	Americans				1436
	Alaska territory				3000
1874	Russians				43
1875	Russians				48
1876	Russians				42
1877	Russians				64
1878	Americans				3148
	Russians				89
1879	Americans				3169
	Russians				20
1880	Russians				700
	Americans				3225
	Americans				6000
	Roger Bros				75
	Russians				187
1881	Russians				124
	Americans				3210
1882	Russians				120
	Americans				3259
1883	Russians				110
	Americans				4502
1884	Americans				4024
1885	Americans				4275
1886	Americans				3604
	Americans				3788
1887	Americans				3095
	Americans				3283
1888	Americans				2496
	Americans				3508
1889	Americans				1795
	Americans				1980
1890	Americans				1633
	Americans				1874
1891	Americans (?)				2369
	Americans				1436
	Russians				175
	Americans				1690
1892	Russians				196
	Americans				921
	Americans				820
1893	Russians				151
	Americans				686
	Americans				717
1894	Americans				623
	Americans				598
1895	Americans				887
	Americans				810
1896	Americans				724
	Americans				720

TABLE 1—(*Concluded*)

Dates of voyages	Captain of ship	Skins taken			Total
		Adults	Cubs	Pieces	
1897	Americans				344
1898	Americans				53
1899	Americans				152
1900	Americans				115
1901	Americans				23
1902	Americans				36
1903	Americans				40
1904	Americans				47
1916	American (?)				1
1917	Americans				2
1918	American				1
1928	Japan				15
1929	Japan				14
1930	Japan				3
1938	American				1

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WHALING ON THE WEST COAST OF NORTH AMERICA, 1911–1938, WITH SPECIAL EMPHASIS ON THE 1937 AND 1938 OPERATIONS AT AKUTAN, ALASKA

By Talbott Denmead and Esther E. Dodd

From 1911 to 1938, inclusive, 30,922 whales—sperm, blue, finback, sei, humpback, bottlenose, right, California gray, bowhead, beluga, and several species not designated—were taken from the west coast of North America. The Alaska catch is included in this figure except for the year 1911, when no figures were available.

More humpback whales were taken during the period 1911–1938 than any other species. The peak was reached from 1921 to 1930 when 6169 humpbacks were taken as against 4884 from 1911 to 1920 and 883 from 1931 to 1938. The catch of sperm whales reached its peak during the 1931–1938 period when 1736 were taken as against 932 from 1921 to 1930 and 840 from 1911 to 1920. A greater number of blue whales were taken in this area from 1921 to 1930, when the catch is shown as 1847, which declined to 349 during the period 1931–1938; the 1911–1920 catch was reported as 1291. A total of 4310 finback whales were taken during the 1911–1920 period as against 3272 from 1921 to 1930 and 1159 from 1931 to 1938. The largest catch for sei whales was shown as 511 during the 1911–1920 period, dropping to 493 from 1921 to 1930, and 33 in the 1931–1938 cycle. The catch of bottlenose, right, gray, bowhead, and beluga whales was considerably less than the catches of the species named above:

Years	*Bottlenose*	*Right*	*Gray*	*Bowhead*	*Beluga*
1911–1920	15	3	1	3	328
1921–1930	8	16	236	2	0
1931–1938	0	4	88	0	0

Besides the species heretofore enumerated from 1911 to 1920, 743 whales of "miscellaneous" species were reported taken; this figure dropped to 715 from 1921 to 1930, and further declined to 51 during the 1931–1938 period.

In studying the catch for the 1931–1938 period it must be remembered bowhead and right whales were protected under the Convention for the Regulation of Whaling of September 24, 1931 (Treaty Series No. 880), this country being a signatory of that Convention; and further, that the Whaling Treaty Act of May 1, 1936 (49 Stat. 1246), placed definite restrictions on whaling by nationals of this country, as did also the Joint Regulations of the Secretary of the Treasury and the Secretary of Commerce of October 16, 1936, superseded by those of May 18, 1938, which were also superseded by those of December 20, 1938. In this connection the Act prohibited the taking and killing of gray whales as well as the other species protected under the Convention, and the June 8, 1937, Agreement, proclaimed by the President May 18, 1938, which supplemented the Convention, also gave to gray whales this added protection. In addition to prohibiting the taking of certain species of whales, the Convention prohibited "the taking of calves or suckling whales, immature whales and female whales, which are accompanied by calves (or suckling whales)." The Whaling Treaty Act established a 60-foot size limit on blue whales, a 50-foot limit on finbacks, and a 35-foot limit on humpbacks. Any whale of these species below those limits is regarded under the Act as an immature whale. Under the London Agreement of June 8, 1937 (Treaty Series No. 933), the size limits were raised, on blue whales to 70 feet, and on finback whales to 55 feet, and a 35-foot size limit was placed on sperm whales. The 35-foot established for humpbacks remained the same. The Protocol of June 24, 1938 (Treaty Information Bulletin No. 108), proclaimed by the

President April 8, 1939, established a limit of 65 feet on blue whales, 50 feet on finback whales, and 30 feet on sperm whales taken for delivery to land stations, provided the meat of such whales is used for local consumption as human or animal food.

The June 8, 1937, London Agreement further closed certain areas in the Pacific Ocean to whaling for baleen whales by factory ships, "and whale catchers attached thereto for the purpose of taking or treating baleen whales." The Protocol of June 24, 1938, extended those closed areas. (See attached map.)

From a comparative analysis of the catch on the West Coast of North America from 1911 to 1938, it is difficult to ascertain what percentage of the decreased catch of blue, fin, and humpback whales from 1930 to 1938 may be attributed to any of these conservation measures, as the Bureau did not collect any statistical and biological data on the subject until enactment of the Whaling Treaty Act and promulgation of Joint Regulations thereunder.

An analysis of the 1937 and 1938 catches at the Akutan, Alaska, station shows that 256 blue, humpback, sperm, and finback whales were processed at that plant during the 1937 season, as against 173 of the same species in 1938. The 1937 and 1938 catches, by species, were:

Year	*Finback*	*Blue*	*Humpback*	*Sperm*
1937	114	41	61	40
1938	65	33	12	63

The 1938 catch of all species except sperm whales decreased. The fact that the catch of sperm whales increased at Akutan during 1938 was not true of the sperm fishery as a whole on the west coast of North America, for the 1938 catch for that area was 315 as against 321 in 1937; nevertheless the sperm fishery of the west coast produced a greater catch in 1938 than any other whale fishery on the coast and showed a lower percentage of decrease.

Twenty of the 256 whales taken at Akutan in 1937 were pregnant, as against 10 of the 173 taken in 1938. In both years in each species—blue, finback, and humpback—female foetuses prevailed, except in the finbacks taken in 1938, among which male foetuses were more numerous. The 1938 catch revealed the smallest foetus, a female measuring 3 feet, found in a 40-foot humpback whale taken September 17, 1938; the largest, also a female, measured 15 feet and was found in a blue whale measuring 79 feet taken August 7, 1938. In the 1937 catch the smallest foetus recorded measured 1 foot 4 inches, taken from a finback measuring 67 feet, captured July 28, 1937; the sex did not appear. The largest foetus was a female measuring 15 feet taken from a blue whale of 80 feet captured September 9, 1937.

The average size of the whales taken at Akutan during 1937 and 1938 is indicated below (measurements in feet):

	Finback		*Blue*		*Humpback*		*Sperm*
Year	*M*	*F*	*M*	*F*	*M*	*F*	*M*
1937	56+	58+	73+	74+	37+	38+	46+
1938	58+	60+	74+	76+	37+	38+	49+

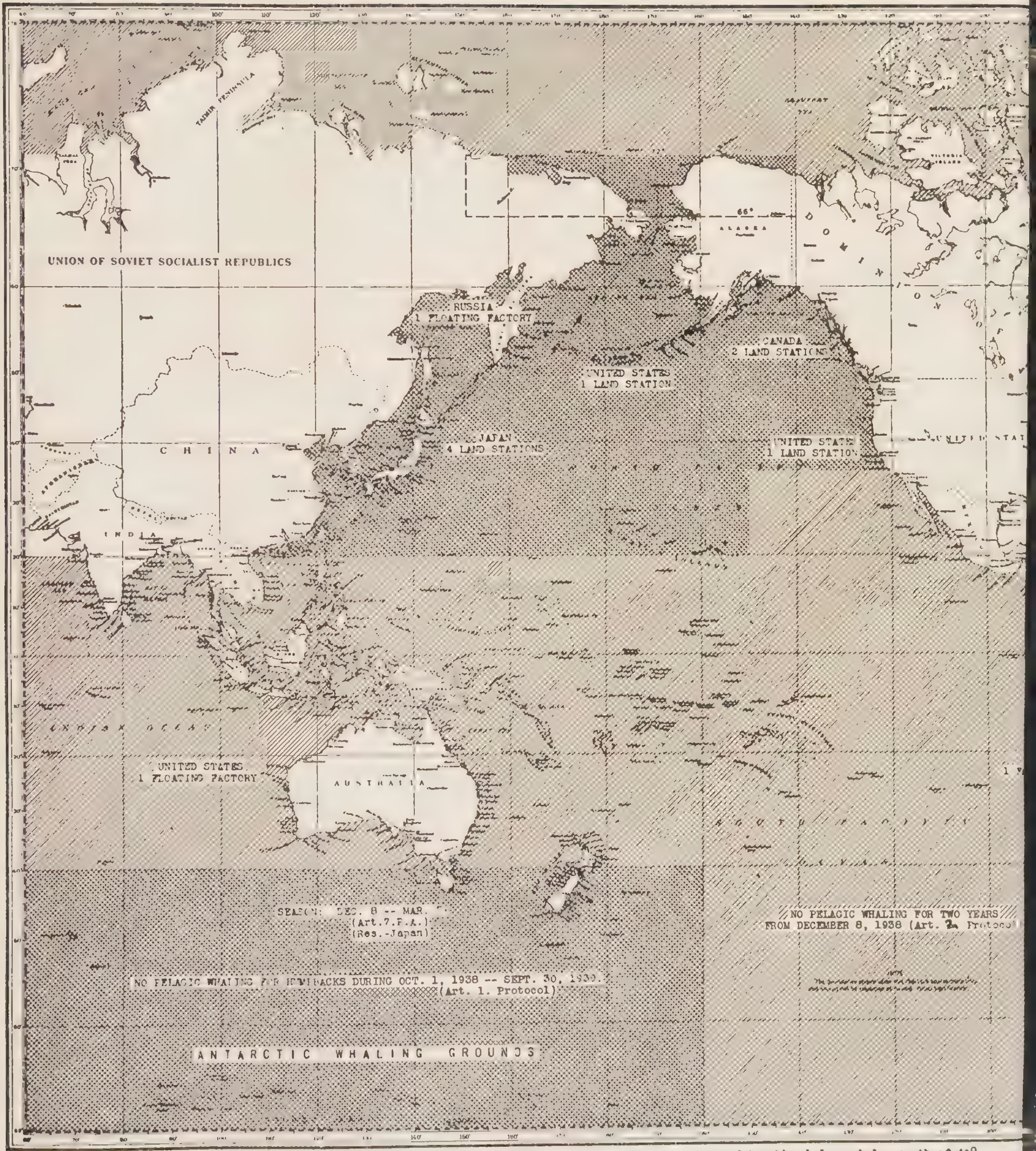
From studies made at Akutan, Alaska, during the 1937 and 1938 whaling seasons, the average production per foot of blue whales appeared to be 1.39 bbl. in 1937 and 1.38 bbl. in 1938. Sperm whales showed an average production in 1937 and 1938 of 1.10 bbl. per foot; finbacks, 0.845 bbl. per foot; and humpbacks, .622 bbl. per foot. The 1938 foot-production figures for finbacks and humpbacks do not appear. While these figures are necessarily approximate because the studies on which they are based represent so small a proportion of

▨ CLOSED TO PELAGIC WHALING UNDER PROTOCOL

▩ OPEN TO PELAGIC AND LAND STATION WHALING UNDER PROTOCOL

WORLD WHALING OPE

IN AREAS DEFINED BY INTER


TAIMIR PENINSULA
UNION OF SOVIET SOCIALIST REPUBLICS
RUSSIA
1 FLOATING FACTORY
66°
ALASKA
DOMINION
CANADA
2 LAND STATIONS
UNITED STATES
1 LAND STATION
CHINA
JAPAN
4 LAND STATIONS
UNITED STATES
1 LAND STATION
UNITED STAT
INDIA
INDIAN OCEAN
UNITED STATES
1 FLOATING FACTORY
AUSTRALIA
SOUTH PACIFIC
SEASON: DEC. 8 -- MAR.
(Art.7.P.A.)
(Res.-Japan)
NO PELAGIC WHALING FOR TWO YEARS
FROM DECEMBER 8, 1938 (Art. 2. Protocol
NO PELAGIC WHALING FOR HUMPBACKS DURING OCT. 1, 1938 -- SEPT. 30, 1939.
(Art. 1. Protocol)
ANTARCTIC WHALING GROUNDS
100°
110°
120°
140°
160°
180°

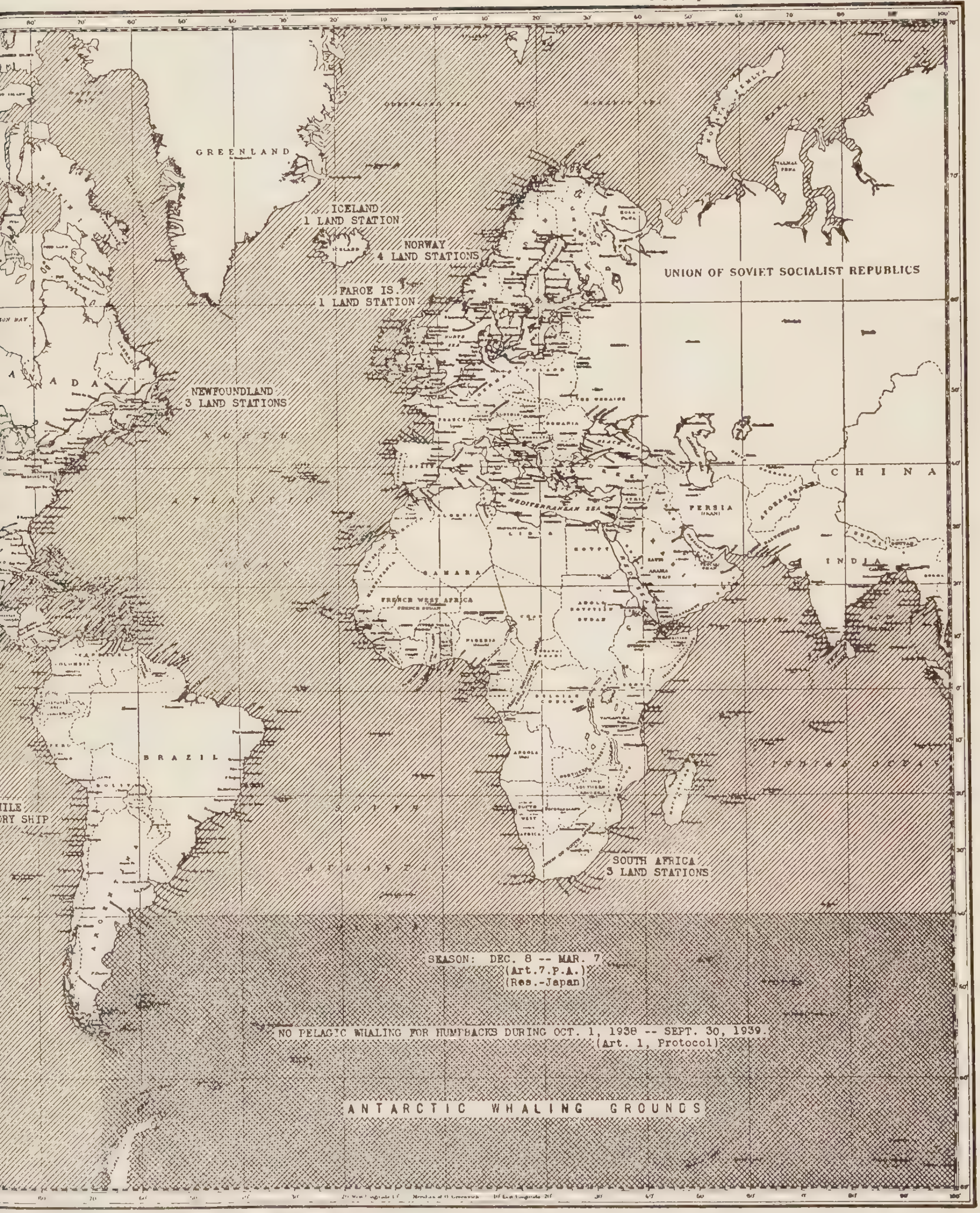
NOTE: No factory ship which has been used for the purpose of treating baleen whales south of 40° south latitude shall be used for that purpose elsewhere within a period of twelve months from the end of the open season prescribed in Article 7 of the Principal Agreement (Art.3(1) Protocol. (Reservation--Japan).

Only such factory ships as have operated during the year 1937 within the territorial waters of any signatory government shall, after the signature of this protocol, so operate, and any such ships so operating shall be treated as land stations and remain moored in territorial waters in one position during the season and shall operate for not more than six months in any period of twelve months, such period of six months to be continuous. (Art.3(2) Protocol). (Only affects baleen whales).

Fig. 1. World whaling ope

RATIONS, 1938-39
ATIONAL CONVENTION

Principal Features Outlined by
Charles E. Lund
Foodstuffs Division
Bureau of Foreign and Domestic Commerce
U.S. Department of Commerce, Washington, D.C.


GREENLAND
ICELAND
1 LAND STATION
NORWAY
4 LAND STATIONS
FAROE IS.
1 LAND STATION
UNION OF SOVIET SOCIALIST REPUBLICS
NEWFOUNDLAND
3 LAND STATIONS
CHINA
PERSIA
INDIA
FRENCH WEST AFRICA
BRAZIL
ILE
RY SHIP
SOUTH AFRICA
3 LAND STATIONS
INDIAN OCEAN
SEASON: DEC. 8 -- MAR. 7
(Art.7.P.A.)
(Res.-Japan)
NO PELAGIC WHALING FOR HUMPBACKS DURING OCT. 1, 1938 -- SEPT. 30, 1939.
(Art. 1, Protocol)
ANTARCTIC WHALING GROUNDS

ANTARCTIC EXPEDITIONS, 1938-39

Nation	Floating Factories	Land Stations
NORWAY	10	0
UNITED KINGDOM	10	1
GERMANY	7	0
JAPAN	6	0
PANAMA	1	0
UNITED STATES	1	0
ARGENTINE	0	1

ions, 1938–39.

the catch of the species named, they do furnish a tentative yardstick for measuring production. The analysis of a tremendous amount of statistical data would be required before the Bureau could recommend a common denominator to be used in ascertaining the per foot production of the various species of whales taken from a particular area. It is even doubtful whether the same common denominator could be used for all areas or during the entire season when whaling is pursued in a given area.

Production at Akutan for 1937 included 520,200 gallons of whale oil, 128,600 gallons of sperm oil, 300 tons of bone fertilizer, and 575 tons of meat fertilizer. Its production in 1938 is reported as 304,800 gallons of whale oil, 181,900 gallons of sperm oil, 216 tons of bone fertilizer, and 396 tons of meat fertilizer.

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THE SHELLFISH RESOURCES OF HAWAII

By C. H. Edmondson and I. H. Wilson

Since mollusks and crustaceans are the two larger groups of marine invertebrates in Hawaiian waters, one might naturally assume that, among a possible 1500 species of the former and approximately 400 species (Brachyura and Macrura) of the latter, there would be a goodly number of each group suitable for human consumption. Such an assumption, however, is not well founded. Although both mollusks and crustaceans are abundant in the shore waters of Hawaii, relatively few native forms of shellfish play any significant part in the food economy of the human population.

Taking cognizance of this natural deficit, private citizens of Hawaii have attempted from time to time to introduce and establish shellfish of various sorts. Since about 1920, government agencies of the territory have also taken a hand in these ventures, with more or less success.

One of the earlier shellfish immigrants that has become an economic asset in Hawaii is a small but excellent clam of Oriental origin, *Paphia philippinarum*. It probably first filtered into Hawaii in small numbers many years ago. Seeking possibilities of a valuable source of food in this bivalve, responsible persons made possible, in 1920, a consignment of ten barrels of specimens from Japan. They were planted in Kalihi Basin, Pearl Harbor, and Kaneohe Bay, Oahu. They grew and reproduced exceptionally well in all localities except Kaneohe Bay, where little progress was made. The species, locally known as the "Damon clam" because one Mr. Damon was instrumental in procuring the consignment from Japan, has supplied a steady market demand in Honolulu for about eighteen years. In 1937 nearly 400,000 young specimens of the Damon clam were removed from Kalihi Basin and Pearl Harbor and distributed to various localities on Kauai, Hawaii, Lanai, Maui, and Oahu. They have adapted themselves very successfully in nearly all the new habitats.

Another Oriental clam, *Cytherea meretrix*, somewhat larger than the Damon clam, has found favorable habitats in Hawaii and may prove to be a valuable addition to our shellfish fauna. The species is already beginning to be a commercial asset. The term "Pismo clam" is sometimes applied to this bivalve, owing to a general similarity in form to the California species of similar name, though much smaller. In February, 1939, a shipment of 20,000 young specimens of *Cytherea* was received from Japan and planted in Kaneohe Bay, where rapid growth has taken place.

Several attempts to introduce edible mollusks into Hawaii from the California coast have not been successful, for one reason or another. In 1927 a small shipment of abalones was planted in Kaneohe Bay, where they seemed to do well at first but eventually disappeared. During 1928 quantities of cockles and Pismo clams from California were planted in various localities on windward Oahu without success.

That Hawaiian waters once supported oysters of considerable size and in great abundance is shown by fossil deposits in raised reefs. About the shores of Pearl Harbor may be seen great beds of the extinct *Ostrea retusa*, which compared favorably in size with the eastern oyster, *Ostrea virginica*. Other and much larger oysters once existed in Hawaii, but not in large numbers. Several species of *Ostrea* are now living in the shore waters of Hawaii. *Ostrea sandwichensis* is a very abundant form in many localities. All living members of the genus, however, are too insignificant for human food.

In addition to the occasional efforts of private citizens of Hawaii who have introduced oysters and tried to grow them without much success, it has long been the ambition of officials of the Fish and Game Division of the Territory of Hawaii to succeed in establishing in the islands an edible oyster of good size and quality. Since 1920, oysters from America, Australia, and Japan have in turn been imported and given fair trials in what seemed to be ideal habitats. Plantings of *Ostrea virginica* in Pearl Harbor were quite successful and there is evidence that spawning and setting of spat occurred. The species has not, however, become a local commercial product as a result of these efforts. Quantities of an Australian oyster, *Ostrea cucullata,* were planted in Kaneohe Bay, but all died within six months. During March, 1939, more than one million spat of the Japanese oyster, *Ostrea gigas,* were planted in Kaneohe Bay. Exceptionally rapid growth has taken place during the past four months and it is hoped that this species may become permanently established in Hawaii.

A small native pearl oyster, *Pteria nebulosa*, has received some local attention in recent years. It grows abundantly in Kaneohe Bay, and during 1937 more than 50,000 pounds of young specimens were distributed to localities on Kauai, Hawaii, Lani, Maui, and Oahu. Although this species, which grows to a diameter of about four inches, is not widely used as food at the present time, it has possibilities in that direction and doubtless would become a much more important factor should a scarcity of other sea foods arise.

Other species of mollusks which contribute to the food supply of at least a part of the citizens of Hawaii include the *Octopus*. Thousands of pounds of these cephalopods are sold annually in the Honolulu fish markets and other large quantities pass directly from the sea to the consumer. Two species supply this demand, *Polypus marmoratus* and *Polypus ornatus*. Locally they are almost universally and incorrectly called "squid." Neither reaches a very large size, usually between two and three feet in length with the tentacles extended.

A true squid, *Sepioteuthis arctipinnis,* is frequently seen in the fish markets. This small species, reaching about one foot in length, seems to be plentiful about Hilo, from which locality the Honolulu supply usually comes.

Two or three species of gasteropods are consumed in rather large amounts by certain fractions of our population. A fresh water species, *Neritina granosa,* is plentiful in certain streams of Molokai, from which source the supply comes. Apparently the species never became established on Oahu. About one year ago, the late Charles Judd, Chief Forester of the Territory of Hawaii, caused a quantity of this species to be transplanted from Molokai to Oahu. It is hoped that it may become adjusted to its new habitat. Two large, limpetlike species of the marine genus *Helcioniscus* are relished by many of our local population. Occasionally these species are sold through the markets, but quantities are consumed directly from the sea, and they doubtless have a much greater part in the general food supply than market sales indicate.

The paucity of native edible mollusks in Hawaii is paralleled by the absence of a good supply of a first-rate native crustacean shellfish. In the abundance of shoal-water Brachyura about our shores there is no native species that even approaches the cancer crabs of the west American coast in qualifications that mark a valuable brachyuran shellfish. But two species of crabs are constant market products in Hawaii, *Portunus sanguinolentus* and *Podophthalmus vigil.* Both are swimming crabs, plentiful and of good quality, but small in size, with very slender chelae and a meager amount of edible material in each specimen. Occasionally other crabs, some of fair size, find their way to the market, but usually singly or but a few individuals at a time.

The large mantis shrimp, *Lyssiosquilla,* is an excellent edible shellfish but rarely taken and costly in retail price. *Panulirus,* the "spiny lobster," is properly conserved by legal restrictions and is one of the valued edible shellfish, although somewhat limited in supply.

An assortment of small shrimps and prawns may occasionally be seen in the markets. Adult specimens of *Metapaeneus marginatus* six inches in length may be taken in quantity by fishermen during certain seasons of the year, and several species of *Palaemon* and other genera of small shrimps are included in our local food supply. A small fresh-water prawn, *Atya bisulata,* is dried and in this state is relished by some of our population.

The recent introduction of the crab, *Sylla serrata,* into Hawaiian waters has added a new and probably permanent element to our crustacean fauna. Transplanted into Hawaii from Samoa but a few years ago, it has already become thoroughly established about our shores, entering the estuaries of streams and ascending far up some of the larger rivers.

The crab grows to a considerable size, specimens eight inches in breadth of carapace not being uncommon, and develops large and powerful chelae. It can be obtained in the markets almost daily and has become an important addition to the list of our sea foods.

The population of Hawaii has always depended much upon products of the sea for its sustenance. The almost unlimited variety and quantity of fishes has been the chief part of this supply. In recent years the fisheries have operated farther and farther from shore, owing to the apparent depletion of the shore waters. If the offshore supply of fish should become restricted or entirely eliminated, a severe loss would be felt by a large part of our population.

To conserve and further develop the near-shore sea food resources of Hawaii the proper authorities of the territory are directing efforts in two directions: first, in cultivating to a greater degree native species potentially useful as food; and second, by introducing species from other localities which seem to have possibilities of becoming useful supplements to the native stock.

A RECENT SHIPWORM SURVEY IN HAWAII

By C. H. Edmondson

The current survey of shipworms in Hawaii is a continuation of work on fouling organisms begun in 1935, emphasis now being placed upon wood borers of the genera *Teredo* and *Bankia*.

The destructiveness of the shipworm in Hawaiian waters has long been known, this knowledge resulting in a local opinion that untreated timbers in shoal waters about the islands may stand up for two years but that six months more nearly represents their period of usefulness.

Experience has resulted in the general substitution of concrete for wood in marine construction wherever practical, or of treated timbers for natural ones if wood must be exposed to sea water. Owners of private wharfs supported by untreated piles in Pearl Harbor and Kaneohe Bay are familiar with not only the shipworm, but also with *Martesia* and *Limnoria,* which are also very destructive. Wooden boats are soon damaged in local harbors unless special precautions are taken against the wood borers by keeping the craft well painted and the underwater surfaces unscarred.

A number of previous reports have included information about the shipworms of Hawaii. Among them were that of Atwood and Johnson, under the auspices of the National Research Council, issued in 1924; a systematic treatment of the shipworms of Hawaii, Samoa, and the Philippine Islands by R. C. Miller, also in 1924; and a series of reports by the San Francisco Bay Marine Piling Committee, the last published in 1927. The Hawaiian data for these reports were drawn from three localities, Nawiliwili, Kauai, Pearl Harbor, and Honolulu Harbor, Oahu.

The present investigations were undertaken in the belief that a resurvey might reveal additions to or shifts in the previously known population of shipworms in the islands and that broader and at the same time more detailed presentation of information about local forms was desirable.

In the course of this survey six stations have been established about Oahu: one in Hanauma Bay, one in Pearl Harbor, two in Kaneohe Bay, one on Waikiki Reef, and one in the Ala Wai Canal.

At these stations test blocks of various woods are submerged and lifted at intervals and examined for shipworms. The data sought in these investigations include a determination of the species now active in local waters, their distribution, the rate of growth, periods of spawning, seasonal variation in activity, larval and postlarval development, their behavior under normal and abnormal conditions, their preference for certain woods, and such other information as may be gained.

Up to the present time our test blocks have revealed a possibility of nine species. This number is tentative and further study may reduce it by one or two. One of the most active shipworms in Hawaii is the species determined by Miller (1924) as *Teredo affinis* Deshayes and for which Dall, Bartsch, and Rehder (Bernice P. Bishop Museum Bull. 153, 1938) now suggest the name *Teredo milleri.* The suggestion is based upon an unsupported statement of Roch and Moll (Proc. Malacol. Soc., March, 1931) that Miller's determination is incorrect, and accompanied by a figure purporting to be *T. affinis* but bearing little or no resemblance to that of the type species as illustrated by Deshayes. Although the figure of the pallet of the type species, as illustrated by Deshayes, is not a facsimile of that of a typical Hawaiian specimen, it does, I believe, come within the range of variation, and I shall continue, for the present at least, to call the form *Teredo affinis.* About Oahu the species predominates in Hanauma Bay, on Waikiki Reef, and in the Ala Wai Canal, and also occurs in Kaneohe Bay. In 1924 Miller recorded it from Nawiliwili, Kauai, and from Honolulu Harbor.

In 1924 Miller determined a species taken at Nawiliwili, Kauai, as *Teredo bartschi* Clapp, which was described from Florida the preceding year. The species is now the predominating one in certain sections of Pearl Harbor and Kaneohe Bay, Oahu. Dall, Bartsch, and Rehder (*op. cit.*) have now proposed a new specific name for the Hawaiian form, *Teredo hawaiensis,* and have relegated Miller's determination to a questionable synonym. My observations with respect to this change of name are, first, that the species determined by Miller is undoubtedly the one occurring about Oahu at the present time; and second, that my microphotographs of structural details of this form tally so closely with figures in Clapp's original description of *Teredo bartschi* (Proc. Bost. Soc. Nat. Hist., Vol. 37, 1923) as to leave little doubt that the Hawaiian species is Clapp's *Teredo bartschi.* For the time being, at least, I will so designate it. Attention is here directed to the description of a shipworm in the Philippine Islands by Sivickis (Philipp. Jour. Sci., Vol. 37, 1928) under the name *Teredo bartschi.* Since this name was preoccupied, the Philippine species should be renamed.

Twelve years ago *Teredo parksi* Bartsch was considered the dominant species in Hawaii. It seems to be generally distributed about Oahu but is not now dominant at any station under my observation. Test blocks of 1935–1937 were more highly infested by this species than they have been during the past two years. The species has appeared at nearly all stations, but apparently is being crowded out by *T. affinis* and *T. bartschi.*

The species *Teredo diegensis* Bartsch was first described from San Diego, California, in 1916 (Nautilus, Vol. 30, 1916, and more fully, U. S. Nat. Mus. Bull. 122, 1922). Specimens from Nawiliwili, Kauai, and from Pearl Harbor, Oahu, were determined by Miller in 1924 as *T. diegensis.* Dall, Bartsch, and Rehder (Bernice P. Bishop Museum Bull. 153, 1938) say: "From what we know of the distribution of shipworms we are disinclined to believe this is *T. diegensis.*" These authors therefore propose a new species for the Hawaiian form, *Teredo kauaiensis,* on the belief that the characters given by Miller in his determination were distinct enough from the original by Bartsch to warrant a new name. The Hawaiian form with which I am working is without doubt the one determined as *T. diegensis* by Miller in 1924. Since there has been some confusion about this species, not only in Hawaii, but in California as well, I believe we are justified in retaining the name *T. diegensis* for the Hawaiian form, for the time being at least.

About Oahu *T. diegensis* is not common, but it occasionally appears in Kaneohe Bay, Pearl Harbor, and on Waikiki Reef. In the final report of the San Francisco Bay Marine Piling Committee the query is raised whether the species was introduced into Hawaii from the California coast or whether it had reached California from the Pacific Islands. The species is known to be abundant at Midway Island, a locality which may be highly favorable to its development, more favorable, perhaps, than Kauai or Oahu, where it sparsely occurs. The latitude of Midway is a little farther north of Oahu than it is south of San Diego, the type locality of the species. Boats of many descriptions, including wooden-bottomed fishing sampans of long cruising ability, offer easy transportation among the islands of the Hawaiian archipelago for marine boring organisms.

Evidence from Midway Island indicates that *T. diegensis* is the predominating shipworm in that part of the Pacific Ocean. The Engineer Office of the United States Army, in the course of construction work now being carried on at Midway, noted the presence of shipworms in some of the timbers exposed to sea water, and a section of an untreated Douglas Fir pile eight inches square that was driven close to shore July 1, 1938, and raised March 1, 1939, was sent to Honolulu for inspection. It was almost completely honeycombed by *T. diegensis* and also slightly tunneled by a very large form recently described by Bartsch as *Teredo gregoryi* (Bernice P. Bishop Mus. Bull. 153, 1938). Shells and pallets of both species were obtained from the burrows. Shells of *T. gregoryi* have frequently been taken from drift logs on the windward shore of Oahu and were taken from drift logs at both Midway and Wake Islands by the Tanager Expedition of 1923. The first living specimen of this species appearing in the course of the present survey was taken from a test block from Kaneohe Bay in April of this year (1939). Shortly after that, redwood timbers of a diving platform which had been anchored on Waikiki Reef for nearly two years were found to be heavily infested by *T. affinis*, *T. parksi*, and *T. gregoryi*. Only the shells of the last-mentioned species, however, were obtained; but some of the burrows were 20 mm. in diameter and exceeded 1 ft. in length. Drift logs that reach the Pacific islands of the Hawaiian archipelago are usually Douglas Fir and it is assumed that they have drifted from the northwest American coast, probably Oregon or Washington. On reaching the islands the logs are often perforated by burrows of shipworms 10 to 15 mm. in diameter, indicating that the attack by the borers must have been at or near the beginning of the drift. From these logs on the shore of Oahu I have frequently obtained shells of the *T. gregoryi* type, but never living specimens. Living specimens, however, have reached the Hawaiian Islands as living forms, and have appeared in test blocks and other timbers of known periods of submergence. One of the strange things connected with this species which apparently has drifted to the Pacific islands is that it has not appeared along the northwest American coast. *Teredo gregoryi* closely resembles *T. thomsoni* Tryon and also *T. malleolus* Turton, from each of which Bartsch separates it by some slight differences.

Another easily recognized species, *Teredo trulliformis* Miller, has appeared in the course of this survey, on Waikiki Reef, in Kaneohe Bay, and in the Ala Wai Canal, but only occasionally at either station. Miller reported the species to be common in Honolulu Harbor fifteen years ago. In 1924 Miller described another species from Honolulu Harbor, *Teredo furcillatus;* I have not seen this species.

In the earlier surveys no species of *Bankia* were observed in Hawaii. Within the past few months, however, the activities of two members of this genus have been indicated about Oahu. A species of *Bankia* has recently appeared in test blocks on Waikiki Reef. The determination of this form is still in doubt. The pallet is of the cone-in-cone type with the elements drawn out laterally into slender processes. Fimbriations of the periostracum on one side of each cone present a comblike appearance. The elements of the blade, however, are widely separated. This may be a juvenile characteristic, as the largest specimen so far observed is but 130 mm. in length. There seems to be some resemblance of this species to *Bankia rubra,* described by Sivickis from the Philippine Islands in 1928. From redwood timber submerged for almost two years on Waikiki Reef, there was taken a pair of long, slender pallets of the *Bankia* type. No shells of the specimen were obtained. The pallet of the Hawaiian specimen, which has a very long stem, closely resembles, in general appearance, figures of *Teredo carinata,* Gray (MS, in British Museum; Reeve, Conch. icon., f. 6, 1878). The locality nearest Hawaii from which the British species has been reported is Penang. It is to be hoped that more complete specimens of this form may be obtained in Hawaii.

Another form, possibly a distinct species of *Teredo,* is common with *Teredo affinis* in Hanauma Bay and on Waikiki Reef. This association suggests that it may be an immature form of *T. affinis,* but a conical or truncate lobe at the bottom of the concavity at the tip of the blade of the pallet seems to be a distinct character in specimens up to a length of at least 50 mm., which is the maximum size observed. The pallet of the typical *T. affinis* assumes the general adult form by the time the specimen reaches a length of 10 mm. Furthermore, this unique form becomes fertile when very small, specimens but 10 mm. in length having been observed to be discharging mature larvae. The larvae are larger than those of *T. affinis,* pale brown in color, more oval, and slightly smaller than those of *T. diegensis.* More complete studies of these doubtful forms will be necessary to place them positively in their proper taxonomic position.

Of the eight or nine species of shipworms observed in the course of current survey few are so distributed and so prevalent as to constitute serious local damage. *Teredo affinis,* on the leeward shore of Oahu, is a constant menace to small craft occupying the anchorage at the mouth of the Ala Wai Canal. This drainage canal was constructed from the sea through the Waikiki section of Honolulu for a distance of about two miles, ending blindly. *Teredo affinis* advances up the canal to its head. Test blocks at various localities in the canal are as highly infested by the shipworm as are those on the reef beyond the outlet. The boat anchorage at the mouth of the canal, occupied by a large number of privately owned yachts, is in the track of this ravenous borer.

At our station in Pearl Harbor, at the junction of the east and middle lochs, and in the northeastern section of Kaneohe Bay, the form which I believe to be *T. bartschi* seems to be the predominating species at the present time. It seems to be almost entirely confined to the larger bays of the island, rarely occurring at others of the stations here under consideration. The species is more active in Pearl Harbor than in Kaneohe Bay. The collapse of wooden structures of minor importance within the range of this species, and its savage attacks on test blocks, especially in Pearl Harbor, are indications of its potential destructiveness.

The recent appearance of living *Teredo gregoryi* and of one or more species of *Bankia* introduces additional and perhaps more destructive members to the catalogue of shipworms invading Hawaiian waters.

In computing the rate at which *Teredo* burrows in wood, the time elapsing between the submergence of the timber and the initial attack should be considered. This time doubtless varies with locality, type of wood, and species of *Teredo.* In Pearl Harbor *T. bartschi* has penetrated soft wood to a depth of 2 mm. in 16 days. Attacks of this species in Kaneohe Bay are usually slower, periods of 25 days frequently passing before soft woods are punctured. My records indicate that *T. affinis* has punctured soft wood to a depth of 5 mm. in 26 days. In laboratory cultures of a doubtful species, larvae became affixed to the wood on the second day after leaving the body of the parent, but 10 days elapsed before the shells completely disappeared within the wood.

An estimation of the probable average daily rate of boring of *T. affinis* and *T. bartschi* in soft woods is reached by assuming that 15 days elapsed between the time of submergence of the test block and the complete penetration by the larvae. On the basis of 23 records, for periods ranging from 52 to 230 days at different times of the year, the probable average daily rate of boring of *T. affinis* amounts to 1.79 mm., while that of *T. bartschi* is 1.33 mm., based on the same number of records ranging from 44 to 259 days. Of these two common species *T. affinis* is the more active about Oahu at the present time. In Pearl Harbor *T. bartschi* is almost as destructive as *T. affinis* is on Waikiki Reef, but in Kaneohe Bay infestations by *T. bartschi* are less than in Pearl Harbor, and especially during the winter months there is a marked slowing up of activity at the windward stations.

The behavior of several species of Hawaiian shipworms on subjection to altered conditions has been investigated. When removed from wood, specimens of *T. bartschi* 60 mm. in length have lived in fresh water for 7 hours but not for 8 hours. Individuals from 10 to 20 mm. in length usually die within one hour, although within the wood resistance to fresh water is greatly increased, adults having lived 51 hours but not 70 hours.

In sea water diluted by equal parts of fresh water, specimens of *T. bartschi* 60 mm. in length, out of wood, have lived 28 days. Specimens from 3 to 10 mm. long may live for about 10 days. The resistance of *T. affinis* and *T. parksi* parallels that of *T. bartschi*.

Active larvae of the three species just previously mentioned die at once when transferred to fresh water. In sea water diluted with equal parts of fresh water they are apparently little affected during 75 hours. After this the weaker gradually succumb, some surviving, however, for 10 days but none for 11 days.

An undetermined *Teredo*, mentioned above, develops a relatively large and resistant larva. In fresh water the larvae endure 15 minutes without deleterious effect, all recovering on being returned to sea water, the recovery time being 9 minutes. After 30 minutes in fresh water, 16 per cent of the larvae revived on return to sea water, requiring 30 minutes for recovery, and after 90 minutes in fresh water 2.7 per cent of the larvae eventually recovered. No recovery occurred after 140 minutes in fresh water.

Adult specimens of *T. affinis*, out of wood, are little affected on being exposed to temperatures as low as 6° C. for five or six hours. On ascending temperatures, however, 35° C. is lethal to them in from 30 to 45 minutes.

Larvae of *Teredo* endure low temperatures for extended periods. After a gradual reduction from 23.5° C. to 0° C., in two hours' time, larvae of *T. parksi* recovered activity almost at once on being returned to sea water of normal temperature. Twenty hours at a constant temperature of 0° C. has little serious effect on the larvae. Larvae of *T. bartschi* on rising temperatures are still actively swimming after 15 minutes at 35° C. They are, however, low in the water and show such erratic movements as rapid rotation or rolling over and over. After one hour at 35° C. approximately 50 per cent of the larvae are actively swimming, and on return to normal temperature nearly all recover.

Some species of *Teredo* can be cultured under laboratory conditions. Active larvae of a doubtful species common on Waikiki Reef released in a stender dish will attack wood within 48 hours. In this form the contact is made with the wood by the tip of the extensile foot, which becomes the anchor, this organ gradually growing shorter and thicker as the shell is drawn closer to the wood. From four to ten days were required for the shell to come in contact with the wood so that the cutting could begin. During this time the shell was being modified by the development of a thin lip along the anterior margin on which first one and then a number of rows of low, broad teeth appeared. Usually about seven rows of teeth are formed when the cutting actually begins. The anterodorsal portion of the shell develops more rapidly than the anteroventral, resulting in a differentiation of the anterior lobe. As the shell penetrates the wood further differentiation occurs, additional rows of teeth are formed, the anterior lobe is more clearly defined, and a thin posterior outgrowth marks the position of the auricle.

Shells of free larvae which make no contact with wood become modified in a similar manner, although not to the same degree as those which find opportunity for burrowing.

As a part of the current survey we are attempting by a process of elimination to determine among the native woods of Hawaii those which offer a high degree of resistance to attacks of the shipworm. We will then by an analysis of the woods themselves attempt to find an explanation for that resistance. Preliminary experiments have already eliminated such woods as koa, kou, milo, guava, monkeypod, mokihana, and hibiscus. These offer little more resistance to *Teredo* than do soft woods such as fir and cedar. Most of these are riddled in highly infested waters within 60 or 90 days. Among woods which in preliminary tests have offered an appreciable degree of discouragement to *Teredo* are kamani, ohia, hau, kauila, ulei, and olemea. Some of these have repelled the shipworm for periods of six months, but longer exposure is necessary to test adequately their efficiency in this direction.

Other means of guarding test blocks against the attack of *Teredo* included the use of metal bands, copper and zinc, and the application of toxic paints. Copper bands one-half inch wide placed one-half inch apart are effective in completely repelling the borers or reducing infestation to a minimum over periods of from four to six months. Zinc bands of similar arrangement have no merit, the blocks so treated being destroyed as rapidly as untreated controls.

Toxic paints, under various trade names, have been used extensively and have proved very efficient in protecting test blocks against *Teredo* for periods up to eight months. Some of the cheaper antifouling paints now on the market seem to have equal merit with the more expensive ones. The only assurance private owners of yachts and other small craft in Hawaii have of long use of their boats lies in repeated inspection of the hulls and the frequent application of a good antifouling paint, because the anchorages are, without exception, in waters highly infested with *Teredo*.

The current survey of shipworms in Hawaii may well be continued, we believe, with profit, through more intensified studies of the known prevailing forms, through an increase in the number of stations about Oahu, and through expansion to other islands of the archipelago.

THE SARDINE: INTERNATIONAL ASPECTS OF ITS LIFE HISTORY AND EXPLOITATION

By Frances N. Clark

Sardinops caerulea, the sardine or pilchard, found along the Pacific shores of North America, has been recorded from southern Alaska to the Gulf of California. The region in which it is found in abundance, however, extends only from Vancouver Island southward to midway along the peninsula of Lower California. The distribution of the population throughout this range is very complex, involving not only annual migrations but also differential size movements. The young fish are much more abundant in southern waters than in northern; the adults are found in commercial quantities in the northern region only during the summer and early fall, whereas they occur in abundance in California districts during the fall, winter, and spring.

On the basis of information available at present, the explanation of the greater abundance of young sardines in southern waters lies in the location of the spawning grounds. Exploratory work, which has been carried on chiefly by the California Division of Fish and Game, has demonstrated heavy spawning in waters between Point Conception and San Diego, a fair amount off the northern part of Lower California, and, in some seasons, from Point Conception north to San Francisco. This northward spawning appears to increase in warm years. No sardine eggs have been found north of California, but the region has not been sufficiently explored to demonstrate that some spawning does not take place. The optimum temperature for spawning lies between 14° and 18° C., and this probably explains the concentration of spawning in the south-central part of the range of the species. Waters to the north are too cold and those to the south too warm.

Young sardines ranging from a few millimeters to 150 mm., standard length, are found in large numbers along the sandy beaches of Lower California and of California from Point Conception to San Diego. In central California, especially Monterey Bay, fish of these sizes are also quite numerous. Off northern California, Oregon, Washington, and British Columbia we have only scattered records of their occurrence; and similarly in the Gulf of California. More concentrated collecting efforts would undoubtedly reveal a more frequent occurrence of young sardines in these outlying regions, but the overwhelming numbers south of Point Conception establish the chief nursery grounds for the sardine in the waters off southern California and northern Lower California.

The length of time that the young fish remain on each nursery ground before moving to another locality has not been determined. It may be only a matter of a month or so or it may be as much as six months. Circumstantial evidence indicates, however, that the movement between adjacent localities takes place early in the life of the young fish and that within their first year they may have experienced a movement of several hundred miles. In each locality the smallest fish are found close to shore and as they increase in size they tend to move into deeper waters.

Maturity is reached by a few individuals when they are about 160 mm., standard length; about 50 per cent of the population is mature at a length of 180 to 190 mm., and practically all fish spawn at 210 mm. Accurate age determination for the sardine has proved difficult, but presumably a small percentage of the population spawns at the end of the second year, many at the end of the third, and nearly all at the end of the fourth.

The migrations of the sardine have been studied in many ways. The first theory of extensive movements was based on the observations of greater abun-

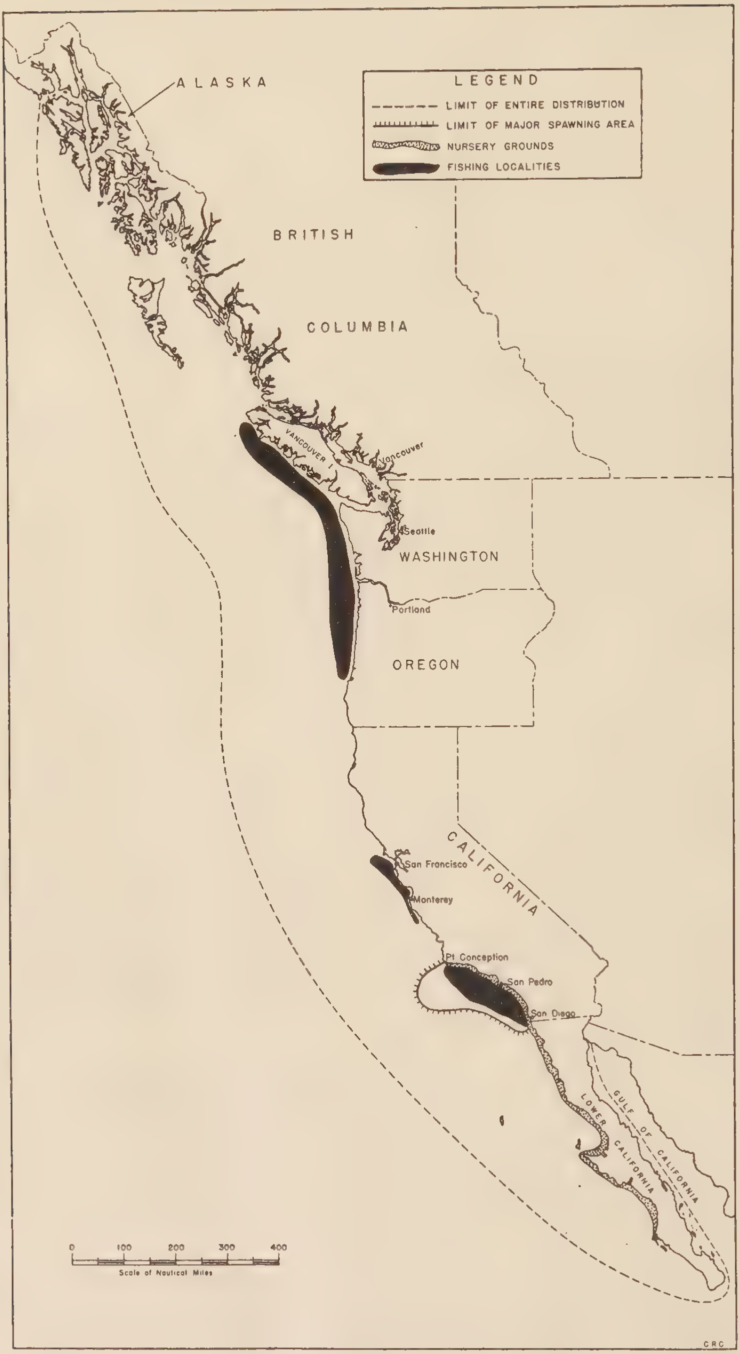

ALASKA
LEGEND
LIMIT OF ENTIRE DISTRIBUTION
LIMIT OF MAJOR SPAWNING AREA
NURSERY GROUNDS
FISHING LOCALITIES
BRITISH
COLUMBIA
VANCOUVER I.
Vancouver
Seattle
WASHINGTON
Portland
OREGON
CALIFORNIA
San Francisco
Monterey
Pt Conception
San Pedro
San Diego
LOWER CALIFORNIA
GULF OF CALIFORNIA
0 100 200 300 400
Scale of Nautical Miles
CRC

Fig. 1. The maximum distribution of the sardine along the Pacific coast of North America, the major spawning area, the chief nursery grounds, and the fishing localities.

dance of young fish in southern waters and their comparative scarcity in northern regions. As the fishery for the adults developed and as the sizes caught by the fishermen were analyzed, it became evident that not all sizes are equally available to the fishermen throughout the year. In British Columbia the fishery relies chiefly on the largest fish, 230 mm. long or greater, and these sizes are found in commercial quantities from about June to October only. Much the same situation holds for the fisheries of Washington and Oregon. In central California from August to November the fishery relies mainly on sizes between 170 and 220 mm. Beginning sometime in November or December, the larger fish, comprising sizes taken during the summer in northern waters, appear on the central California fishing grounds and are caught until the latter part of February or March. In southern California the same size changes occur as in central California, but the small fish, from 170 to 220 mm., do not appear until October or November and the largest sizes until late December or January. These annual size changes indicate an annual migration of the population north and south along the North American coast with the larger fish making a more extensive northward movement than do the small sardines.

This mixing of the population was further confirmed by racial studies, chiefly vertebral counts, which yielded no significant differences for adult sardines taken at various localities from British Columbia to California.

The final demonstration of an annual migration was made by the recovery of tagged fish. Sardines tagged off southern California in February and March have been retaken off Vancouver Island the following July and August. Conversely, fish tagged off Vancouver Island in July and August have been recovered off central California in December and January and off southern California in February and March. Similar exchanges have occurred between California and Washington and Oregon and between central and southern California. Furthermore, of California tagged fish which comprise a large size range, only the larger individuals have been retaken in the northern waters of British Columbia, Washington, and Oregon, whereas the smaller sizes as well as the larger have interchanged between central and southern California.

Thus the life history of the sardine may be summed as follows: Most of the spawning probably occurs in southern California and northern Lower California waters from March to June. The young fish remain on nursery grounds in the same southern region for perhaps six months or a year. In their second summer, if not earlier, they exhibit some northward movement and the extent of this northward movement increases year by year. The largest and oldest fish reach the waters off Oregon, Washington, and British Columbia. This summer northward migration is followed by a southward movement in the fall and winter preparatory to the spring spawning. Maturity is attained in the second, third, or fourth year and the life course is run out somewhere between the tenth and fifteenth year.

Throughout its entire life and along its entire range of distribution the sardine population is exploited by man. In Lower California and southern California the young fish in their first year are used extensively in the live bait fisheries. The tuna fishermen use sardines in their operations on the high seas adjacent to the Mexican coast. In southern California these young fish supply much of the bait for marine sport fishing, and for the commercial live bait fishing for tunas, mackerel, yellowtail, white sea-bass and barracuda. In central California the young sardines, and to a greater amount the adults, are used in the dead bait fisheries.

In British Columbia, Washington, Oregon, central California, southern California, and northern Lower California the adolescent and adult sardines are exploited for canning and for reduction into meal and oil. The development of this industry along the Pacific coast of North America has been startling in its rapidity. Although adequate statistics are not available for more than twenty years, these two decades practically cover the history of the industry. From its inception until 1934, sardines were fished only in the waters off Vancouver Island and off central, southern, and Lower California. In 1935 exploitation was started off Oregon, and in 1936 off Washington.

Throughout the past twenty years, 1918–1938 (see table 1), the total annual catch has fluctuated as economic conditions have varied, but with the exception of two slight setbacks with the economic depressions of 1920–1922 and 1930–1932, there was a continual annual increase until 1936. In 1918 and 1919 the annual catch along the Pacific coast was approximately 80,000 tons. This represented the first peak of production for the then infant industry and was caused by the increased demand for fish associated with the World War. The second peak was reached in 1929 at 400,000 tons, five times as great as in 1919. The next high point occurred in 1936 with a catch of almost 800,000 tons, twice that of 1929 and ten times as great as that of 1919. This rapid expansion can be attributed almost entirely to the fishery in California waters. Throughout the two decades the catch from California waters in any year was never less than 70 per cent of the total, in 14 years it was more than 80 per cent, and in 10 years more than 90 per cent.

TABLE 1

Annual Catch (in Tons) of Sardines Used for Canning and Reduction along the Pacific Shores of North America

Year	British Columbia	Washington	Oregon	California Shore Plants	California Floating Plants	Total
1918	3,640	......	......	78,830	......	82,470
1919	3,280	......	......	76,940	......	80,220
1920	4,400	......	......	59,260	......	63,660
1921	990	......	......	29,670	......	30,660
1922	1,020	......	......	46,700	......	47,720
1923	970	......	......	79,080	......	80,050
1924	1,370	......	......	121,340	......	122,710
1925	15,950	......	......	157,650	......	173,600
1926	48,500	......	......	143,370	......	191,870
1927	68,430	......	......	171,140	......	239,570
1928	80,510	......	......	210,130	......	290,640
1929	86,340	......	......	325,890	......	412,230
1930	75,070	......	......	247,220	3,810	326,100
1931	73,600	......	......	150,650	31,520	255,770
1932	44,350	......	......	156,090	55,220	255,660
1933	4,050	......	......	254,900	58,300	317,250
1934	43,000	......	......	451,820	108,670	603,490
1935	45,320	......	26,230	414,760	133,120	619,430
1936	44,450	6,550	14,200	477,760	254,010	796,970
1937	48,080	17,200	16,660	445,720	90,030	617,690
1938	51,770	26,480	16,990	467,810	43,890	606,940
Total	745,090	50,230	74,080	4,566,730	778,570	6,214,700

Statistics for the catch from Mexican waters are not available except for 1938, when 2160 tons were taken.

The British Columbia industry made its greatest catch in 1929, when 86,000 tons were taken. In the past five years the annual landings have varied from 40 to 50 thousand tons. The Washington industry has operated for the past three years only, and in 1938 took 26,000 tons. Oregon's operations cover four

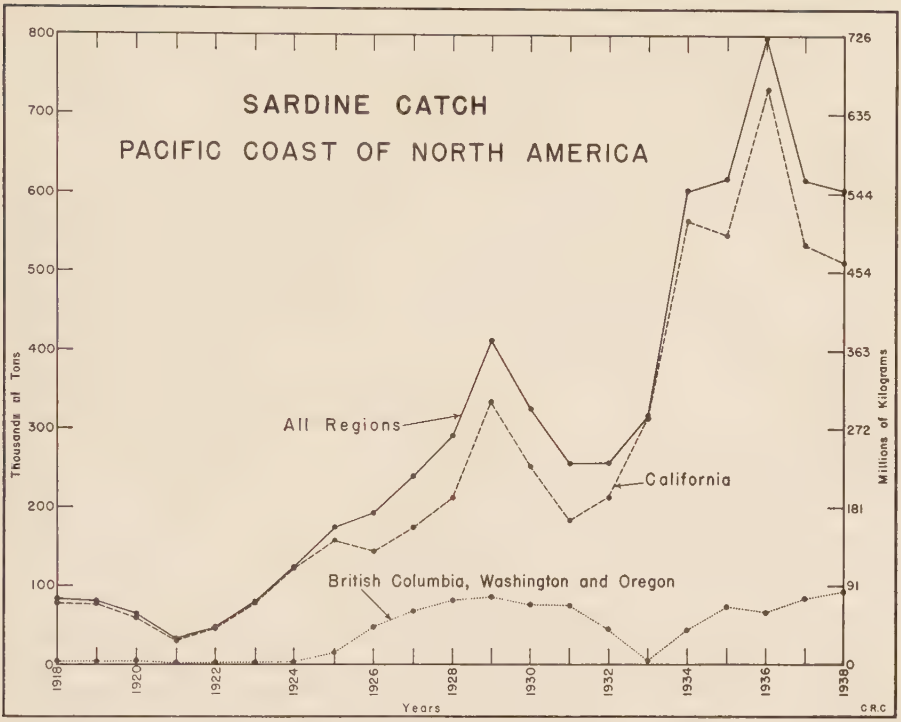


Fig. 2. The annual catch of sardines for canning and reduction along the Pacific coast of North America, omitting small tonnages taken in Mexican waters.

years. In 1935, 26,000 tons were taken, and in the three succeeding years 14,000 to 17,000 tons. These small tonnages, in comparison with the catch in California waters, which since 1924 has never been less than 100,000 tons, clearly demonstrate the important rôle the California fishery plays in the changing abundance of the sardine population.

Sardines are used in large numbers for canning, but the reduction to oil and meal has always been the most lucrative phase of the industry. The California Division of Fish and Game, realizing that a too rapid expansion holds many potential dangers, both economic and biologic, held its industry to a somewhat reasonable expansion until about 1930. This was done by limiting the use of whole fish for reduction into oil and meal to only a small proportion of the total catch. To avoid these restrictions imposed by California, a ship was equipped in 1930 to reduce sardines three miles off the California coast. The enterprise proved successful and more ships entered the reduction phase of the industry. In 1936 these ships took 250,000 tons, which was 32 per cent of the entire catch along the Pacific coast. In the succeeding years the activities of the floating reduction ships grew less and less, due to increased labor costs, more strict maritime regulations, and greater difficulty in finding fish. By the end of 1938 all the ships had ceased operations off the California coast.

To compensate the California shore plants which were having to meet the competition of the reduction ships, the California authority modified its policy of limiting to a very low level the amount of sardines used for reduction purposes. In the last two or three years the restrictions have been so liberal that shore plants have been permitted to reduce practically as much fish as they could obtain. This liberalization of reduction permits made possible the unprecedented expansion of the industry in the last five years.

The effect on the sardine population of this intensive fishery is a matter for grave consideration. Present information indicates that the annual catch seriously exceeds natural replacements. Because of the migratory habits of the population, heavy fishing in one locality adversely affects the supply in all regions. Canada, the United States, and Mexico are all interested in maintaining an adequate supply. But in California only is the sardine fishery a major phase of the fishing industry. This is because sardines of all sizes are found in abundance in these waters and because they can be fished off the California coast for a longer portion of each season than in any other region. It is the behavior of the sardine that makes possible this tremendous California fishery in contrast to the much smaller fisheries in other localities of the sardine's range.

The gravity of the situation is such that the California Division of Fish and Game has urged the stabilization of the catch at some fixed total for each fishing season. It is not possible to state definitely what this total should be, but 200,000 to 300,000 tons has been suggested for the California fishery. This was the size of the California catch at the time that the first signs of overfishing became evident. It also represents the approximate amount the California plants could can and market if no straight reduction were permitted. It may be too large a tonnage, and possibly it is too small. Undoubtedly no fixed amount should be applied over a long term of years. If the population recuperates under a restricted total tonnage, in subsequent years a higher unit may be feasible. In addition, the sardine population has been found to vary in abundance with the success and failure of spawning survival. This may also necessitate a varying total tonnage over a period of years.

The material presented in this paper has been drawn from many sources. The life history is summarized from the works of the Fisheries Research Board of Canada, the Department of Fisheries of British Columbia, and the California Division of Fish and Game. The Fish Commission of Oregon has also contributed to the tagging program. The statistics of the catch have been supplied by the Canadian Bureau of Statistics, the Washington State Department of Fisheries, the Oregon Fish Commission, the United States Bureau of Fisheries, the California Division of Fish and Game, and the Mexican Department of Forestry, Game, and Fish. The aid of all these organizations is gratefully acknowledged.

Detailed reports of the studies on the sardine may be found in the publications of the California Division of Fish and Game, and the investigations carried on by Canada have been reported in the publications of the British Columbia Provincial Fisheries Department and of the Fisheries Research Board of Canada.

STUDIES ON THE JAPANESE SARDINE

By Ikusaku Amemiya

There are two kinds of sardines in the North Pacific: one, the Japanese sardine, *Sardina melanosticta* (Temminck et Schlegel), which is found in the seas off East Asia; the other, the California sardine, *Sardina coerulea* (Girard), which is found off the west coast of North America. Whether these two kinds of sardines are separable into two species, or are two local varieties of one species, as Günther stated, is a matter of dispute. At present, however, most authors hold the view that they are two independent species although they show many common morphological features. It is true that they are very nearly allied with each other notwithstanding that their distribution is separated by a vast area of the Pacific Ocean. The difference between the two kinds is not great, so that whether the erection of the two different species is adequate or not depends upon the opinions of taxonomists.

According to the present author and others, there are some differences between the two sardines. The average number of vertebrae in the Japanese sardine is 50.68 (Amemiya, Aikawa, and Nakai); in the California sardine it is 51.63 (Hubbs, Clark, and Hart). Thus the number of vertebrae, on the average, is just about one more in the latter than in the former.

The ventral scute of the two sardines shows some difference in its form. It is composed of three parts, the axial part or spine and the lateral parts. In the Japanese sardine the axial part is slenderer and shorter than in the California sardine. In the former the lateral part has a thin, triangular, broad blade at its base, its distal part tapering into a long spine, whereas in the latter it has no enlargement at its base and forms simply a spine from the base to the tip.

Both the Japanese and the California sardines have several short gill-rakers on the gill arch. In this they are quite similar to each other, and both equally differ from the European sardine, which possesses no short gill-rakers. With regard to the number of short gill-rakers it seems that there exists some slight difference between the Japanese and the California sardines. In the former we can enumerate 7–9 gill-rakers of varying length on the first arch; the latter, 6–7.

Distribution of the Japanese sardine.—The Japanese sardine is very widely distributed in the waters surrounding the Japanese Empire (fig. 1) from Kyûsyû in the south to Saghalin as well as the Okhotsk side of Hokkaidô in the north, including both the Pacific and the Japan Sea sides of Japan proper, the east coast of Korea, and the Coast Territory, although in the winter season the distribution is much limited in the middle and southern parts of this range. The sardine, however, is not found on the west coast of Korea and in the Inland Sea. The temperature of the water inhabited by the sardine ranges from 12° to 25° C. or a little higher.

As the sardine is a neritic fish, it does not migrate far from the coast into the oceanic region of the Pacific, staying within 10–15 sea miles from the coast. Since, however, the Japan Sea is neritic over its entire area, the fish can go farther, 30 sea miles or more off the coast, but not so far as the California sardine, which, according to American authors, can go 200 sea miles from land.

The Japanese sardine usually migrates along the coast, very often haunting and entering deep into bays and inlets.

Fishing ground.—Like the distribution of the Japanese sardine, its fishing ground is very wide, covering all the coastal region of the Empire. The Japanese sardines, however, differ in size and nature, especially their fat content, according to different fishing grounds and seasons.

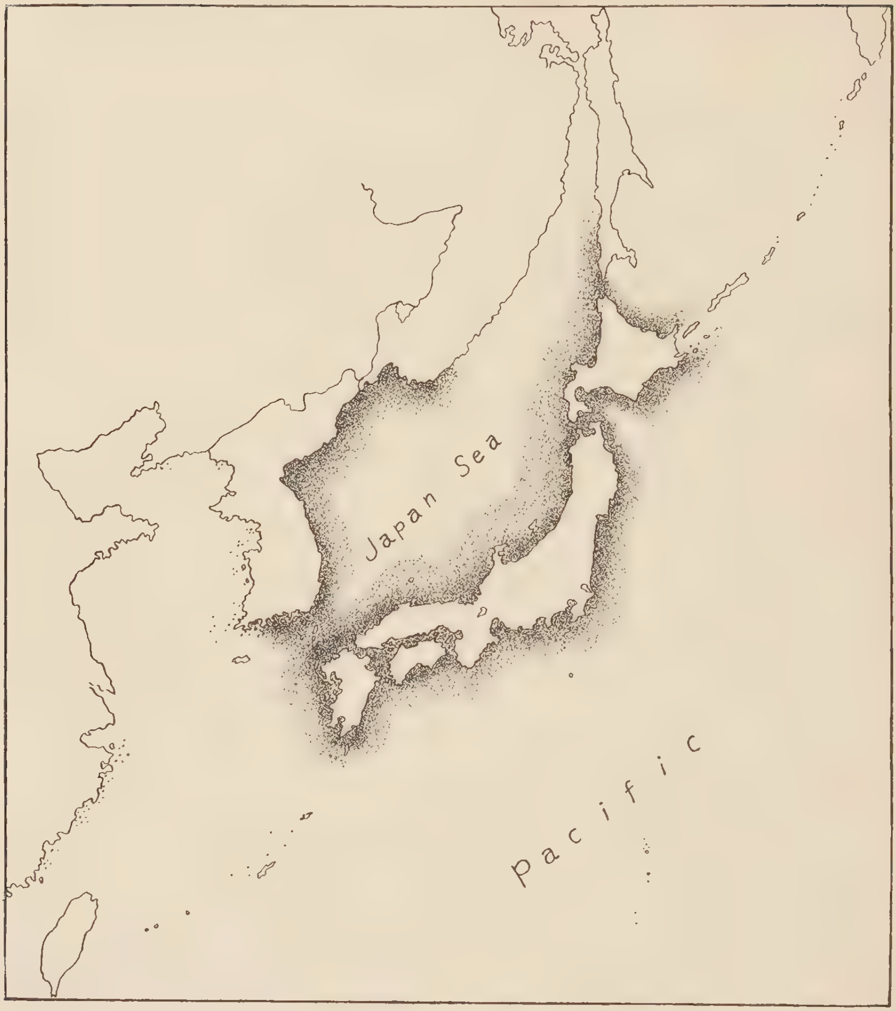


Fig. 1. Distribution of the Japanese sardine.

Generally speaking, in the southern district large fish are fished in the winter and early spring from December to March, and middle-sized fish in the fall, while the small fish are scanty and irregular in their amount of catch. In the Pacific side of central Japan large fish are fished in the spring, March to May, the middle-sized fish in the fall, and small fish in the summer. In the northern part, that is, in Hokkaidô and Saghalin, only the catch of large fish is abundant in summer and autumn; of middle- and small-sized fish, much less. In the Japan Sea large fish are caught in the western region in the spring, February to May, in the central region from April to June, and in the northern region in June and later. In the waters off the east coast of Korea large fish of high fat content are fished abundantly in the fall from September to November, and in the season there is rich fishing of the sardine. Generally, sardines caught in the fall and in the northern districts contain much fat. In all regions the sardine fishery is prosecuted only in the waters near the coast, within at most 20 sea miles from the land.

Number of vertebrae.—The number of vertebrae in the Japanese sardines varies from 47 to 53, these extremes being rather exceptional. Only a few fishes having either 47 or 53 vertebrae are found among several hundred individuals, so they are insignificant statistically. Fishes having 51 vertebrae are predominant, amounting to 60.47 per cent of the whole; those having 50 vertebrae come next, 35.18 per cent; then those having 52 vertebrae, 3.53 per cent, and those having 49 vertebrae, 0.73 per cent. The rest, that is, fishes having 47, 48, and 53 vertebrae, are all very small in number and not worth special mention.

The mean value of the number of vertebrae shows a slight discrepancy: according to Amemiya, 50.66 ± 0.55 (6256 individuals); according to Aikawa, 50.70 ± 0.55 (12,000 individuals); and according to Nakai, 50.68 ± 0.0037 (3945 individuals); average, 50.68 (22,201 individuals).

On the other hand the mean value of the vertebral number varies according to fish schools at different localities and in different seasons. By statistical study of several hundred sample batches collected from different fish schools, it is revealed that the mean value of one school is 51.00 ± 0.53 at the maximum, while that of another is 50.13 ± 0.61 at the minimum, so that there is in these numerical figures not much significance statistically when standard deviation is taken into account.

It is also revealed by the study of the vertebral number that its mean value has a tendency, though only in a slight degree, to increase in the samples taken from the north district compared to those from the south, and similarly in the samples from the Japan Sea compared to those from the Pacific.

Age composition of the sardine schools.—As the size of the sardines in the commercial catch differs according to seasons and localities, it is presumable that the sardine schools differ with regard to the age groups composing them. In fact, from study of age composition, using several hundred sample batches collected all over the Empire, it is known that on the Pacific side the majority of the commercial catch consists of the I-age and the 0-age groups with some portion of the II-age and a much smaller amount of the III-age, while in the Japan Sea and in the northernmost part of the Empire the commercial catch is chiefly composed of the II-age group with a high proportion of the III-age and the I-age group, the 0-age group being much less. Hence it is quite certain that in the Japan Sea fishes older by one year than those in the Pacific live and compose the majority of the fish stock.

The reason why such a condition exists is explained by the fact that a large number of young sardines (0-age and I-age) immigrate from the Pacific into the Japan Sea, passing through straits connecting the two waters, and when they have once immigrated into the Japan Sea, most of them stay therein, not coming out again into the Pacific.

A similar condition is also revealed by the study of spawning schools of the sardine. The spawning schools in the Pacific, so far as our investigation reaches, are composed of 70 per cent of the I-age fishes, 15 per cent of the II-age ones, and 1 per cent of the III-age ones, and the rest of younger ones, while spawning schools in the Japan Sea are composed of 57 per cent of the II-age fishes, 24 per cent of the III-age ones, 19 per cent of the I-age ones, and the rest insignificant in percentage. So, although the frequency polygon of the body length shows quite similar form in the Japan Sea and in the Pacific, yet that of the Japan Sea is translated towards the side of the larger body length, as is shown in figure 2.

Spawning and growth.—Some part of the Japanese sardines spawn in the stage of the 0-age, that is, about the end of the first year of their existence, but most of the spawning fishes are older ones. The spawning ground covers a

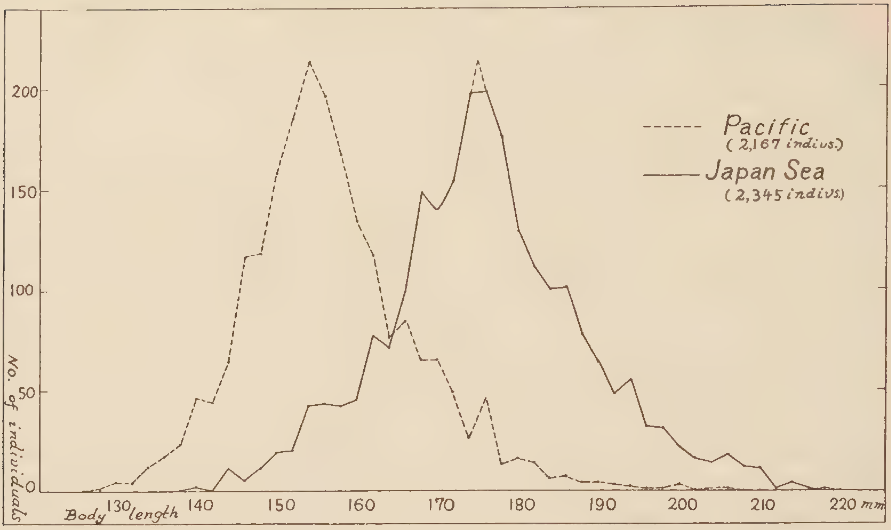


Fig. 2. Frequency polygons of typical spawning schools. (Body length measured without caudal.)

wide range of waters on both the Pacific and the Japan Sea sides, from Kyûsyû to the middle part of the Empire, but not in the seas off the northern part and off the east coast of Korea, where in both seas the water temperature is too low for spawning in the spawning season. The suitable temperature for spawning is about 13°–18° C. As the Japanese sardine lives in the neritic region only, spawning occurs near the coast and not far from land.

The spawning season lasts from January to May, earlier in the southern districts, and later in the northern. The young fishes are irregular in their development, differing with localities and even among schools in the same place at the same time, since spawning lasts for a long time and the fry and whitebait are floated by the water currents or migrate far from the spawning place.

The following two figures (figs. 3 and 4) show the growth rate of Japanese sardines as a whole. The figures have been prepared from results of studies using samples of several hundred batches, each of which consisted of about 150–200 fishes collected at 25 stations all over the range of the sardine distribution. Samples thus collected are statistically treated and their age is determined chiefly by scale reading.

As figure 3 denotes, the body length in the 0-age fishes shows a fairly wide range of variation, but as the fishes grow or as they become older, the variation of the body length decreases gradually. On the contrary, the body weight shows just the reverse condition, as is clear from figure 4. This wide range of variation in the body weight of old fishes is explained by the fact that the amount of the fat content in the old fishes varies with the fishing grounds.

Fishing methods, amount of catch and utilization.—Several fishing methods are used in Japan for sardine fishing. Purse seine, set net, gill net, and drag net are the chief fishing gears. Of these the purse seine is most commonly used. The amount of catch of the sardine does not show much fluctuation and is about 1,700,000 tons annually. The greater part of the catch is sent to the reduction plants, where it is made into fishmeal, fish guano, and sardine oil. Only a small part of it is used for human food either raw or preserved. Canned sardines of various styles, such as the tomato sardine, the oil sardine,

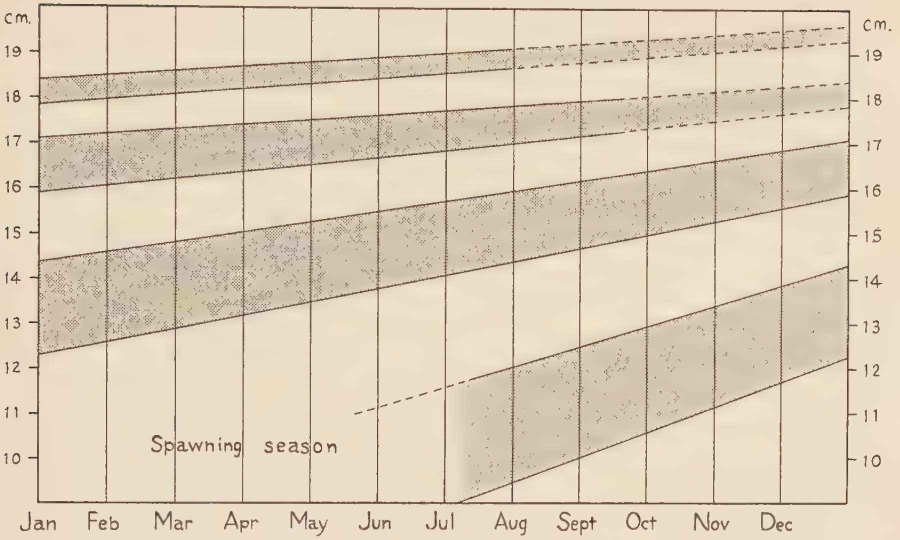


Fig. 3. Relation between body length (without caudal) and date of catch.

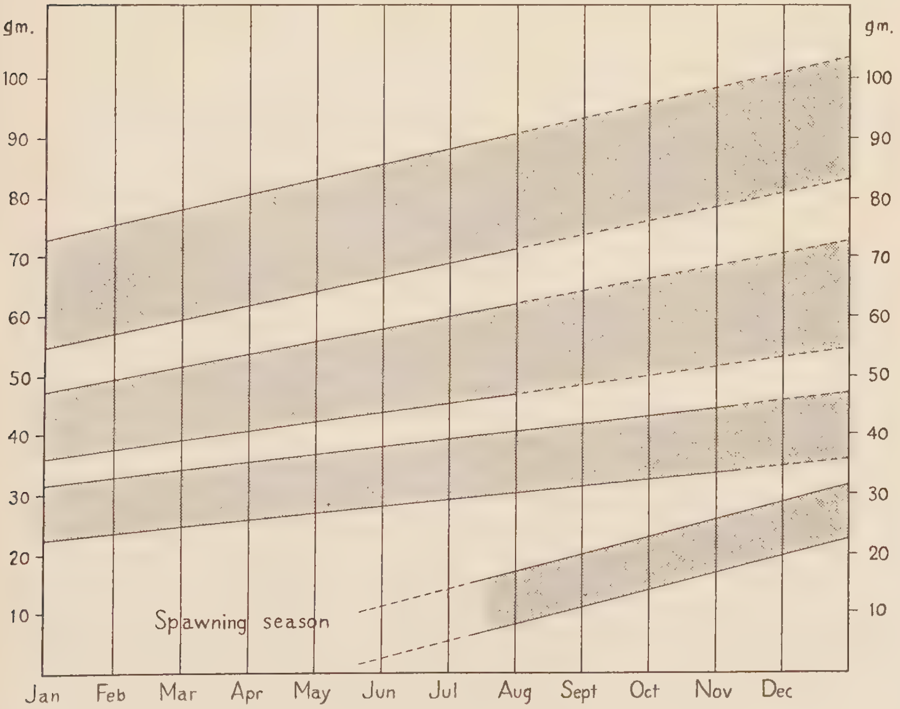


Fig. 4. Relation between body weight and date of catch.

and others, are manufactured in large amounts in factories all over the Empire. They are exported mostly to foreign customers. Only a small part of them are consumed at home.

MARINE ECOLOGY OF THE PACIFIC SALMON

By F. A. Davidson

There are five principal species of Pacific salmon, namely, the king (*Oncorhynchus tschawytscha*), the sockeye (*O. nerka*), the coho (*O. kisutch*), the pink (*O. gorbuscha*), and the chum (*O. keta*). There is also a species of salmon peculiar to Japan, commonly called cherry salmon (*O. Masou*), but owing to its limited distribution it will not be considered in the discussion which follows.

The Pacific salmon are anadromous, spending part of their lives in the sea, where they undergo over 95 per cent of their growth, and part in the streams, where they spawn and die and where the young remain for varying periods of time before migrating to the sea. The length of time the young spend in fresh water depends upon the species, some remaining from one to four years and others leaving shortly after the absorption of the yolk sack.

Only meager information is available concerning the activities of the salmon while in the sea. The young collect in schools of immense size in the inside waters before migrating to the sea and the adults return from the open sea in similar aggregations. Dense schools of pink and chum salmon fry have been observed in the inside waters of southeastern Alaska from 25 to 50 yards in width and extending over an area of 100 yards in length. Since these fry are only 1½ inches in length such schools are composed of millions of individuals. Similar aggregations of red salmon fingerlings have been observed in the waters of Bristol Bay near the mouths of large rivers. Although the adults tend to break up into small schools as they migrate through the inside waters, dense schools of adult pink salmon have been observed 10 to 25 miles offshore, ranging in size from 50 to 100 square yards. Similar schools of pink salmon have occasionally been observed in the larger channels such as Icy Straits and Frederick Sound in southeastern Alaska. At the present time the Bureau of Fisheries is carrying on experimental fishing in Bristol Bay to determine the degree of schooling of the red salmon in the open waters.

Since the coho and king salmon are caught extensively by the troll fishery, information is available concerning the depths at which these species live while in the open sea. Reports from this fishery show that these species are caught frequently as far offshore as 50 miles and at depths from 25 to 75 fathoms. Unfortunately the other species of salmon do not enter the troll fishery to any appreciable extent, but, like the kings and cohos, they no doubt frequent the subsurface waters during their sojourn in the sea.

The native distribution of the Pacific salmon is confined almost entirely to the temperate and arctic waters of the North Pacific. They are found in the streams along both the North American and Asiatic coast lines within similar geographic limits. On the North American continent Monterey Bay, 70 miles south of San Francisco, California, is the southernmost limit of their common occurrence, although a few specimens have been taken at odd times as far south as the Ventura River, California. From here, they inhabit the coastal streams, in varying degrees of abundance, northward along the continent to Kotzebue Sound in Bering Strait.

Chum salmon have been reported in the Mackenzie River of northern Canada and in the Lena River of northern Siberia. These rivers flow into the Arctic Ocean. From the Lena River, the northernmost point of occurrence on the Asiatic continent, the chum salmon are found to a limited extent southeastward along the Arctic shores to the Chucknee Peninsula in Bering Strait. From the Anadir River just south of the Chucknee Peninsula all species are present in varying degrees of abundance in the coastal streams southward along the continent to the Amur River. The range of the pink and chum salmon extends farther southward to the Tumen River in northern Korea, which is the southernmost occurrence of the salmon.

All species other than the chinook salmon are found in the coastal streams of Sakhalin, Hokkaidô, and Kurile Islands and the northern shore of Honshu Island. The range of the pink and chum salmon extends farther southward on Honshu Island to the Tonegawa River near Cape Inuboye on the eastern shore, and to the Omonogawa River near Akita on the western shore.

The North Pacific Ocean within the native range of the salmon varies widely in both temperature and salinity. Surface temperatures vary from 20° C. at the southern limits of the range to 0° C. at the northern limits. Subsurface temperatures at 200 meters vary from 10° C. at the southern limits to slightly below 0° C. at the northern limits. The surface salinities vary from 35 parts per thousand at the southern limits to 29 parts per thousand at the northern limits. Therefore the Pacific salmon have developed a tolerance to wide differences in both temperature and salinity within their native marine habitats.

In studying the distribution of the individual species within the entire range it was found that the chum salmon have the widest distribution and are reported at the limits of the range on both the North American and Asiatic continents. The pink salmon have been reported from southern limits, but do not extend into the arctic region as do the chums. The sockeyes and cohos are more or less intermediate in their distribution and the kings are the most restricted, this being especially true on the Asiatic continent. It is interesting to note that the chum and pink salmon are the most widely distributed. This may be due in part to their greater tolerance to temperature and salinity and in part to their brief fresh-water life history. Since these species use the streams only for the incubation of the eggs, the young do not remain any length of time in fresh water and are therefore not subjected to the extreme environmental conditions that are found in the streams at the southern and northernmost limits of their range.

In the study of the tolerance of animals to environmental factors within their native habitats it is quite often found that although they may be able to tolerate wide differences in these factors within their native range, there are, nevertheless, limits beyond which tolerance does not extend. This seems to be so with respect to the tolerance of the Pacific salmon to temperature and salinity. Through attempts to transplant the Pacific salmon in many parts of the world it has been found that they react unfavorably to temperature and salinity conditions in the sea beyond the upper limits of these factors found within their native range.

THE INTERNATIONAL ASPECTS OF THE HALIBUT FISHERY

By Richard Van Cleve

Compared to the fisheries of the North Atlantic, those of the Northeastern Pacific are relatively undeveloped and will undoubtedly continue to expand with an increase in population along the shore of the Pacific and with an increasing world demand. With respect to the North Pacific halibut, expansion, as in the North Atlantic, will ultimately be followed by need of regulation in order to conserve the fisheries. Persons interested in conservation will probably agree that with respect to many of our marine fisheries international coöperation will be essential to accomplish such an objective. It is therefore of interest to examine the halibut and its fishery which is being regulated under an international agreement, and to inquire into those biological and commercial features of the species and its fishery that render it suitable for such treatment.

The biological investigations and later the regulation of the fishery carried out under the treaty between Canada and the United States are noteworthy alone as examples of international coöperation. However, the problems that are encountered in the investigation and control of the halibut are not peculiar to the species, but are the same as will be encountered in the fisheries for other North Pacific species. Therefore the international investigation of the halibut is important as showing to future investigators the problems that must be met.

The North Pacific halibut fishery began in 1888 with the opening of the railroads connecting the Northwest with the eastern markets. The total annual catch rose from that time to a maximum of over 63 millions of pounds in 1915. After 1915 the production decreased with depletion of stocks until it reached the minimum of 44 millions of pounds in 1931, a low point that was due partly to the depression and low prices but principally to the low level of abundance to which the stocks had been reduced. A small catch of 39 millions of pounds in 1918 may be ascribed to the war. With regulation the fishery has been stabilized at about 49 millions of pounds annually, which in 1938 had a value of over $4,000,000 to the fishermen. In 1935, the last year for which complete figures are available, the North Pacific produced over 58 per cent of the world's halibut.

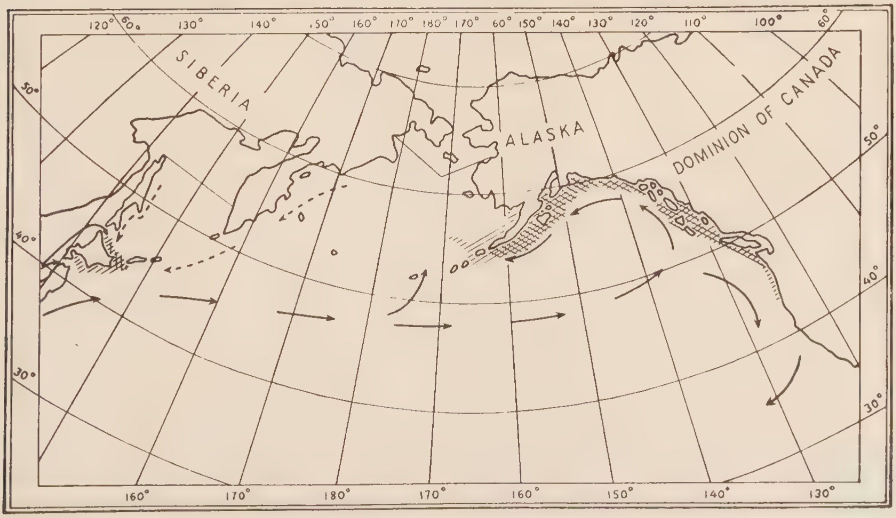


Fig. 1. The halibut banks in the North Pacific Ocean. The banks producing the most halibut are cross hatched.

In the Northeastern Pacific this important species is international in both its biological and its commercial aspects. It is distributed along the coast lines of the United States, Canada, and Alaska, occurring for the most part outside the three-mile limit. The peculiarities of its early life history, the migrations of adults, and consequent separation of stocks in no way correspond to the national boundaries.

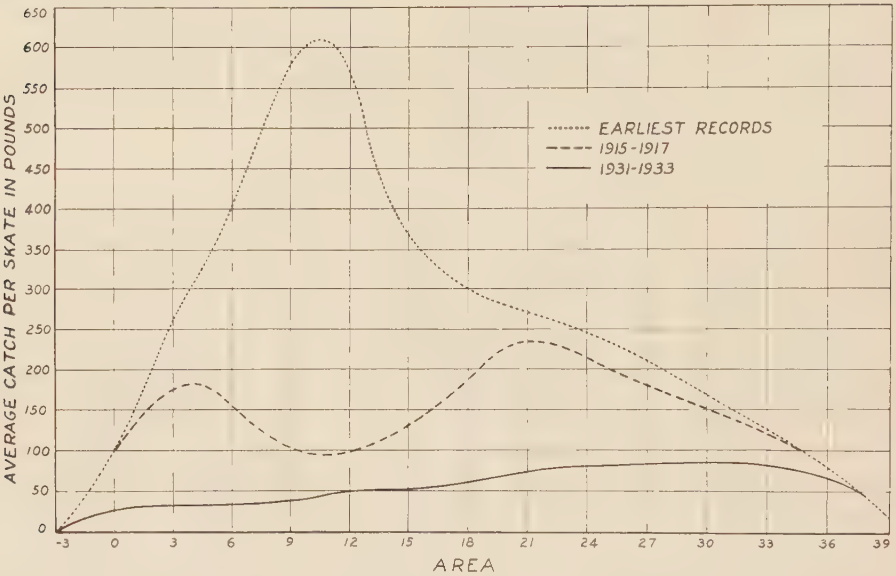
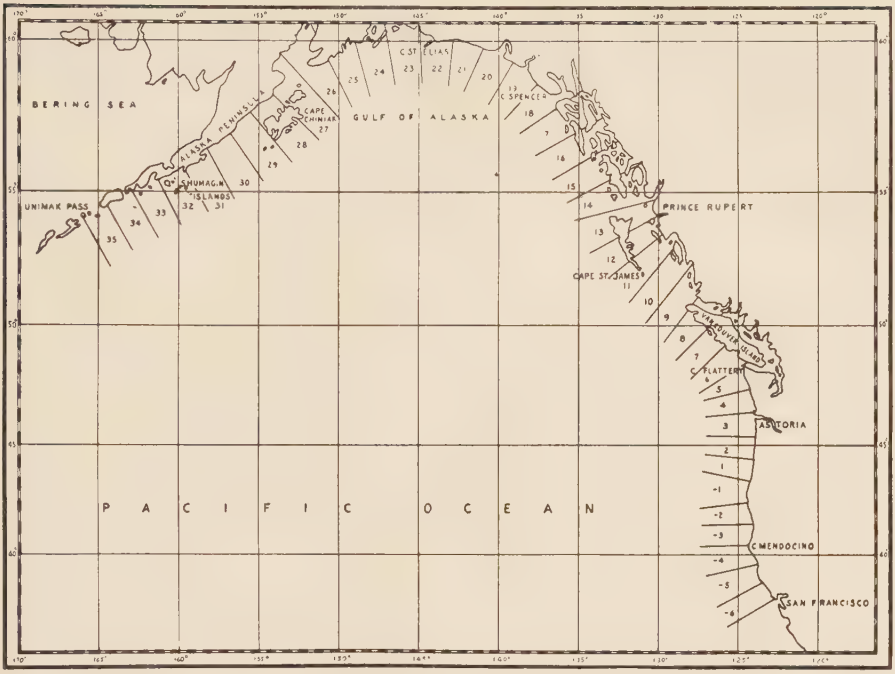


Fig. 2. The distribution of abundance along the Pacific coast of America as shown by the average catch per unit of gear in each area. The location of the areas along the coast is shown in figure 3.

The distribution of halibut in the North Pacific is shown in figure 1. Thompson and Van Cleve (1936) found that the distribution is associated in general with the water temperature at the bottom on the banks. Halibut were found to occur in regions characterized by temperatures of 3° to 8° C. Suitable conditions are found along approximately 2500 miles of the western coast of North America between northern California on the south and Bristol Bay on the north. This region includes the entire coast of British Columbia and the Gulf of Alaska as well as the northern half of the west coast of the United States.

Results of a closer study of the density of the halibut populations along the American coast are shown in figure 2, in which the density of population is measured by the catch in pounds per unit of gear at various stages during the depletion of the halibut fishery. The area numbers along the axis of abscissae correspond to 60-mile-wide zones along the coast. No. 3 lies just north of Cape Mendocino on the California coast; No. 6 includes the mouth of the Straits of Juan de Fuca; No. 14 lies just north of the northern British Columbia boundary in southeastern Alaskan waters, and No. 34 lies off Unimak Pass. (See fig. 3.) Plainly, the greatest numbers of halibut occurred originally along the coasts of British Columbia as is shown by the earliest catch records in areas 8 to 14. During the early years of the fishery these areas produced practically the entire catch for this coast, both American and Canadian.

Study of the migration, growth, and racial characters, as well as of the


BERING SEA
ALASKA PENINSULA
UNIMAK PASS
SHUMAGIN ISLANDS
CAPE CHINIAK
GULF OF ALASKA
C ST ELIAS
C SPENCER
PRINCE RUPERT
CAPE ST JAMES
VANCOUVER ISLAND
C FLATTERY
ASTORIA
C MENDOCINO
SAN FRANCISCO
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-5
-6
60°
55°
50°
45°
40°
170°
165°
160°
155°
150°
145°
140°
135°
130°
125°
120°

Fig. 3. Statistical areas defined by the International Fisheries Commission for the halibut fishery.

early life history of the species, has shown that the halibut inhabiting this coast line in reality consists of two stocks or populations which are biologically independent of each other. The migration studies of Thompson and Herrington (1930) showed that the adult stock west of Cape Spencer, or area 18, which forms the principal part of the catch there is freely migratory within that area. But though they carry out widespread seasonal migrations within that region, few of the halibut—approximately 1 per cent per year—find their way into the regions to the southeastward. The slower growth and larger head of the fish living west of Cape Spencer give further evidence of the separation. (See Thompson and Herrington, 1931; Thompson and Bell, 1934.) Moreover, the drift of the eggs and young has been found to maintain this segregation during the early life history. (See Thompson and Van Cleve, 1936.)

On the other hand, the stocks of immature fish found remaining on the banks along the coasts of southeastern Alaska and British Columbia in general remain within the confines of relatively limited areas. The adults that form the small spawning stocks remaining there are more migratory. Those found on the Whaleback ground off the northern end of the Queen Charlotte Islands make considerable migrations into the southeastern Alaska region, indicating that the stocks in southeastern Alaska form a unit with those off the British Columbia coast.

It is not surprising, therefore, to see in figure 2 (1915–1917 curve of abundance) that the early intensive fishery along the coast of British Columbia and southeastern Alaska (areas 6–17) depleted the stock on these banks but had little effect upon the abundance in areas to the north and south. The condition illustrated by the curve of abundance for 1931–1933 resulted from the widespread and intense fishery that developed after 1923.

Moreover, studies of the ocean currents and distribution of eggs and young over the spawning banks indicate that the nursery grounds off Masset on the north end of Graham Island and off Timered Islet in southeastern Alaska are both supplied with young from the Whaleback and Cape St. James spawning grounds.

The halibut is thus international in its distribution along the outer banks. It is scattered along the coasts of Canada and the United States. Although it is divided into two independent units, one of these overlaps the coasts of British Columbia and southeastern Alaska. The problem of its biological investigation is, therefore, necessarily an international one and requires that persons charged with this work be not limited by national boundaries.

TABLE 1

A. 1938 Halibut Catch by Area and Nationality

	Area 1	Area 2		Area 3		Total	
		Pounds	Per cent	Pounds	Per cent	Pounds	Per cent
U. S.	706,411	13,814,671	59.0	22,820,005	89.7	37,341,087	75.4
Canada	....	9,576,519	41.0	2,623,208	10.3	12,199,727	24.6
	706,411	23,391,190		25,443,213		49,540,814	

B. Number of Men and Boats and Boat Tonnage Engaged in Halibut Fishing during 1938

Country	Men		Boats		Tonnage	
	Number	Per cent	Number	Per cent	Tons	Per cent
U. S.	1822	72.6	339	68.2	6229	76.0
Canada	686	27.4	158	31.8	1962	24.0
	2508		497		8191	

Note: The figures for the catch in area 1 are not final and further corrections may change them. The others are final figures obtained from the files of the International Fisheries Commission.

Like most deep-sea fisheries, the North Pacific halibut fishery is also international in character though it has one peculiarity in this regard: it is exploited only by the American and Canadian fishermen, who have so far enjoyed a monopoly. The landings of the two countries for the year 1938 are shown in table 1, with the numbers of men and boats of the two nationalities. The area numbers refer to the large regulatory areas. Thus area 1 in the table includes the banks south of Willapa Bay in statistical area 4, figure 3; area 2, the region between Willapa Bay and Cape Spencer in statistical area 18; area 3, the region between Cape Spencer and Cape Sagak on Umnak Island.

It is interesting to note that the fishery is shared roughly in proportion to the number of men and boats employed, in spite of the fact that the tonnage figures indicate that the Canadian boats are on the average only two-thirds the size of the American. It is also of interest that the Canadians have increased their share of the total catch from 14.4 per cent in 1932 to 24.7 per cent in

1938, from only 2 per cent of the area 3 fish in 1932 to 10.4 per cent in 1938. There is therefore a tendency toward a more equal sharing of the catch.

The landings are even more equally divided between Canadian and American ports. Since 1919 an average of 48 per cent of all halibut landed on this coast has been handled through Canadian ports. Although the American fish is shipped through Canada in bond, the Canadians profit by the handling and shipping of it.

Beside the fact that the fishery is shared by two nations, the boats fish on the same grounds outside the so-called three-mile limit, where approximately 87 per cent of all the fish are taken. The distribution of the 1938 catch by areas inside and outside three miles from shore is shown in figure 4. All the inside catch in areas 14 to 18 south, which includes all of southeastern Alaska, is landed by American boats which bring in 65 per cent of the American catch from these areas. The halibut landed from the inside waters in these areas also made up 72 per cent of all fish caught inside the three-mile limit. In the areas outside of 14 to 18 south only 4.1 per cent of the 1938 catch came from inside waters.

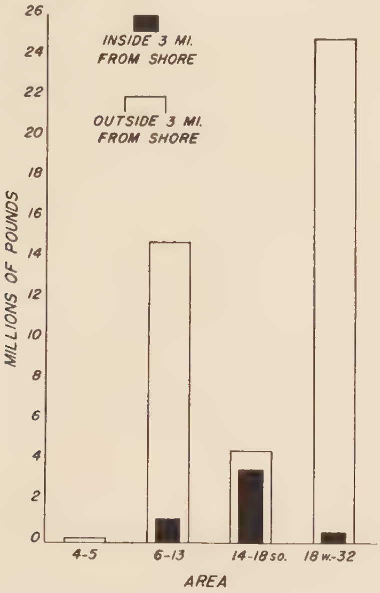

Fig. 4. The number of pounds of halibut taken inside and outside of a distance of three miles from shore in 1938.

Outside of southeastern Alaska, which produced only 14.6 per cent of the 1938 catch, the fishery depends upon the banks which lie more than three miles offshore.

Since the inside waters play such a minor rôle in the North Pacific halibut fishery, it is plain that without definite control of the outer banks the fishery is open to unregulated exploitation by any country other than the United States and Canada. Indeed, only good will and the close commercial relationship between America and Great Britain has deterred British companies from sending refrigeration ships with fleets of tenders to the halibut banks off this coast.

If international control should collapse, the additional strain on the stocks that would result would cause the abundance to fall again as it did during the 1920's and the populations that are being carefully built up through the self-denial and prudence of the Americans and Canadians would be quickly dissipated.

Both biologically and economically the halibut is international and it is only logical that both biological investigations and regulations are internationally controlled. This results in a unified and efficient program of investigation as well as in a flexible plan of control that is easily adjusted to the needs of the halibut and its fishery. The advantages of such international programs are so obvious as to need no further discussion. What must be recognized is that the problems of investigation and conservation of all other species exhibiting the characteristics of international distribution and of an international fishery carried on outside the three-mile limit must be accorded the same type of treatment if we are to avoid the dangers and confusion that arise when the fisheries are left to the mercy of sectional interests.

Of even broader interest than the international regulation is the fact that with complete control of the fishery made possible by an international treaty, an opportunity has been presented of regulating a fishery with the objective of obtaining a sustained yield at the maximum level of productivity of the banks. The principles involved in this problem are well understood and have been adequately treated by Baranof (1918), Thompson and Bell (1936), and Thompson (1937), and need not be discussed here. The success of this experiment will demonstrate the possibility of maintaining a cheap and plentiful supply of food for all time. With the inevitable increase in population of the Western Hemisphere, the importance of such a food source to our national economy cannot be overestimated.

It is also of importance in that it points the way for the treatment of all other fisheries. The myth of inexhaustibility of our fishery resources has been only too well refuted by the experience of the European nations in the North Sea, to cite only one example. A laissez-faire policy of expecting the fishery to adjust itself gradually to the changes in abundance of the fish by shifting of interests to other species, etc., has proved to lead eventually to disaster for the industry.

It is becoming more apparent as fisheries investigations progress that the sea fisheries must be farmed just like any other crop. They must be regulated according to the potential productivity of the banks and of the species inhabiting them. This potential productivity can be evaluated only by widespread biological investigations and in the end by trial by the actual regulation based upon the natural history of the species involved. Biological investigations that are required for species exhibiting characteristics of distribution, growth, and of the fishery such as those shown by the halibut will require international coöperation, and subsequent regulation can be carried out most efficiently by some such arrangement as the Halibut Commission. This regulation cannot be carried on successfully without full control of the fishing banks out to the edge of the continental shelf.

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THE FACTORY SHIP

By R. H. Fiedler

The idea of the factory ship as a fishing tool is not new, for several types of fish processing have been done aboard fishing craft or mother ships for centuries. The exploits of these ships have had a profound influence on the civilized world. They were forerunners of colonization and empire. They assisted in expanding trade and commerce. At one time the product of their expeditions found its way into almost every home in the land. They brought about the depletion of one of the world's greatest fisheries. Truly they have had a marked influence upon civilization, and now the exploits of the modern version of this romantic craft are causing men and nations grave concern lest they disrupt the economic and biologic balance of the world's fisheries.

The beginning of the factory ship dates back to the latter part of the seventeenth century. At that time salt-cod fishing vessels or "factory ships" from the Old World conducted operations on the fishing banks off what is now Newfoundland, the Maritime Provinces, and the New England states. Attention was directed to these banks by the early explorations of Cabot in 1497. He brought back to England glowing accounts of the great abundance of fish in the western North Atlantic and it was not long before fishing vessels from his native land were operating in this area. Soon they were joined by vessels from other Old World countries. According to Thomas Jefferson, a commercial fishery for cod was well established here by 1517 or 1519, and by 1577 the French had 150 cod-fishing vessels in these waters; the Spanish, 100; the Portuguese, 50; and the English, 15.

During those years fishing was conducted along the coast. The harvest was landed in the fresh condition at shore stations, where it was salted and dried. In later years, with more intensive prosecution of the fishery, operations were conducted on the offshore banks. Fish so caught were salted aboard the fishing vessel to overcome the adverse factors of time and place encountered in capture of the fish far from shore and to reduce spoilage aboard the vessel of fish so harvested. Thus began the development of the factory ship.

Concurrent with the prosecution of the cod fishery in the New World, colonies were established on shore. Some were temporary, like the fish-curing stations which were abandoned each fall at the conclusion of fishing operations. Others were permanent, becoming fishing villages and then towns and cities. In this category was the Plymouth Colony and others established by the English and the French along our New England coast, the Maritime Provinces, and Newfoundland. The Portuguese and Spanish did not attempt to establish colonies in this region. Rather, they were lured to colonize in Central and South America, where greater wealth seemed obtainable in the gold regions.

For about two centuries after Cabot's voyages the cod fishery in the western North Atlantic continued to be prosecuted by vessels from England, France, Portugal, and Spain. Then, vessels from the latter two countries withdrew, leaving the field to the fishermen of England and France. During the next hundred years these fishermen had many disputes over the fishing rights.

The desire of each country to secure these rights can be readily understood. These fisheries supplied to the mother country a food which was consumed in immense quantities. Also, they served as a training ground for seamen, who were badly needed at that time to strengthen the evergrowing demand for naval personnel.

The disputes led to bloodshed, then war, finally terminating in the withdrawal of France from North American territory except for the tiny islands of St. Pierre and Miquelon off the southern coast of Newfoundland. Along with the cession of territory, France also relinquished many of her fishing rights—although she has continued in the cod fishery to this date, basing operations at St. Pierre.

As the years rolled on, the English fishery was transferred to her colonies in the New World—Canada, Newfoundland, and the United States now carrying on the fishery in these waters. Portugal reëntered the salt cod fishery in 1885, and has continued on a more or less permanent basis ever since.

It is seen, therefore, that the factory ship has been a dominant factor in development of the cod fishery of the western North Atlantic, as well as an important factor in the colonization of the New World. Historically, the fishery was begun about the time of western exploration and discovery, for prior to these operations the fishery was undeveloped except on a very minor scale inshore by the natives.

Along with the growth of this fishery other fisheries drew attention and prospered. The scramble to get more fish and land them in marketable condition led to transferring other processing functions from shore to vessel. Thus, about the middle of the nineteenth century American fishing vessels began using ice rather than salt to preserve the catch at sea. This enabled the landing of fresh fish, a product then more desired by consumers. As a consequence, the salt-fish trade declined. Now most of the catch by American vessels fishing on the western North Atlantic banks is landed in a fresh, iced condition.

Recently, further innovations have been made to process fish aboard vessels. Some vessels are now equipped with mechanical refrigerating apparatus to hold fresh fish aboard in prime condition pending arrival at port. Others have been equipped to freeze the catch at sea. Some of the latter type have been converted from salt-cod vessels, as, for example, a French trawler which operated on the Grand Banks several years ago, freezing the catch as harvested. This newest development, of freezing fish at sea, has promise of becoming increasingly important, not only because it will aid greatly in expanding the radius over which fishing vessels can operate, but also because consumers are demanding more species of fish in a fresh and frozen condition, rather than as salt fish.

Concurrent with the development of the fishery for cod and other fin fishes in the western North Atlantic the fishery for whales reached large proportions. This fishery drew the attention of Dutch and English whalers soon after the early explorations in waters of the New World. It assumed great importance to our early colonial settlements. For instance, the fishery conducted from the tiny Island of Nantucket, according to Thomas Jefferson, gave employment to six thousand men and boys during the latter part of the eighteenth century. At the height of the American fishery it employed, according to Starbuck, "a fleet of seven hundred staunch ships and fifteen thousand hardy seamen."

At first, the colonial whale fishery was prosecuted within a few miles from shore and the whales were brought to port for processing. As the fishery expanded, larger ships were built to pursue the whale in distant waters. These were equipped with machinery and cookers for processing the whales while the vessel operated on the high seas. By reason of their size and equipment, extended voyages were possible far from home ports. Therefore, it was not long before these American factory ships were scouring the seven seas for whales to meet the evergrowing demand for oil to light lamps of the civilized world. Some expeditions from New England ports were made to the South Atlantic off the coasts of Africa and South America. Others rounded the "Horn" to operate in the Antarctic and the Pacific. By 1840 the American whale fishery was firmly established in the Pacific, operations being conducted along the coast of the Americas, off Asia, and as far north as the Bering Sea.

Prior to this time the fin fisheries of the Pacific were little developed. Some fishing was done along shore by the natives, but their primitive vessels and gear were not very productive. The catch had only local distribution, as methods of preservation and means of transportation were poor. At this time Japanese fishermen operated off the coast of their home land, but imperial regulations did not permit them to venture far from shore. In order to assure conformance with these regulations, Japanese law required that all vessels built in Japan and manned by Japanese were to be constructed with an open stern. This made it virtually impossible for Japanese fishing vessels to weather a heavy sea, and therefore their operating range was limited to a few miles of shore. It was only after the visit of Commodore Perry to Japan and the China Sea that the Japanese turned attention to the high-seas fisheries.

On the eastern side of the Pacific some fishing was done by the Indian population in the inshore waters along the North American continent. This was mainly for salmon, a fish easily captured on its homeward migration from the sea into the streams to spawn; and halibut, a fish found on the inshore banks. The catch of these species reached rather large proportions.

With the settlement of our Pacific Coast, commercial fisheries for fin fishes were established and carried on with great vigor. The whale fishery also continued to flourish. The latter, however, was shortlived. Intensive fishing had depleted the whale population in the Pacific, as well as in other oceans where the whaling fleet could operate successfully. This made it increasingly difficult to obtain a catch at a cost which would allow profitable competition with the newly discovered mineral oil then being substituted for whale oil as an illuminant. Thus, the whale fishery declined during the latter part of the nineteenth century, to be resumed again during the second decade of the twentieth century with use of the most highly developed type of factory ship.

Before leaving this discussion of the whale fishery, it is interesting to note that the exploits of our hardy whalemen in their factory ships did much to expand our world trade and commerce. According to Starbuck, the American flag was first unfurled in many foreign ports by American whaling ships. But for their expeditions into the Pacific this ocean might have remained unknown for a much longer time. They discovered many Pacific Islands, and in their footsteps followed Christianity. The fleet supplied officers and men to our navy in time of war and to our merchant marine in time of peace.

As to the fin fisheries of the Pacific by American enterprise, we find their early beginning interwoven with the factory ship. Cobb indicates that as early as 1863 a salt-cod fishing vessel from San Francisco, California, conducted profitable operations near the mouth of the Amur River. In 1864 a vessel of this type visited the Bering Sea, and in 1865 similar operations were conducted around the Shumigan Islands off the Alaska Peninsula.

The early beginning of the salmon fishery on the Pacific Coast also is interwoven with the factory ship. According to Cobb, a salmon cannery was built in 1867 on board a scow which operated for a year or two on the Columbia River, and in 1883 a salmon cannery was installed aboard a vessel which operated in British Columbia waters.

The factory ship also was used during the early period of the Pacific tuna fishery, for in 1917 and 1918 a floating tuna cannery from San Pedro, California, operated off Mexico. This has since been abandoned. Recently, however, many tuna vessels have been equipped with refrigeration machinery to freeze fish aboard.

From a small beginning nearly a century ago, the Pacific fisheries conducted by American enterprise have grown to large proportions. The salmon fishery is now conducted along the North American continent from California to the Bering Sea. The halibut fishery, begun in waters of the state of Washington, has expanded to waters from California to the Aleutian Islands. The pilchard or sardine fishery originating off California now extends to Vancouver Island. A productive herring fishery is conducted along the Gulf of Alaska. The tuna fishery started off California now extends from waters off the state of Washington to below the equator. In addition, important fisheries for some seventy-five other species of fish and shellfish, many with a restricted range, have been developed off the Americas by American enterprise. Some of these fisheries are prosecuted jointly by American fishermen. For instance, fishermen from Canada and the United States prosecute the high-seas halibut fishery and the inshore salmon fishery contiguous to their respective countries.

The fisheries of the Pacific Ocean are shared principally by 23 countries or political units. According to consular and other reports at the Bureau of Fisheries, the annual harvest of these fisheries amounts to nearly 15 billion pounds, or about one-half of the world's fish production. This harvest is valued at about 277 million dollars. The major portion of the catch is made by fishermen from Japan, China, the United States, Siberia, and Canada, in the order named. The leading species by volume are the herrings, including pilchards or sardines; the salmons; and the mackerels, including tuna and tunalike fishes. The catch of these several species amounts to about one-half of the total yield of the Pacific fisheries.

The catch by United States fishermen in the waters of the Pacific during 1937, according to figures from the Bureau of Fisheries, amounted to about 2½ billion pounds, valued at over 43 million dollars.

In recent years the highly mechanized factory ship has had a prominent place in the further development of the Pacific fisheries, as well as the fisheries in other parts of the world. Vessels of this type now perform almost every type of fish processing, including icing, freezing, salting, canning, and the manufacture of meal and oil. They are staunchly built to withstand rough weather and stormy seas. They range in size from fishing vessels of under 100 net tons with self-contained processing equipment to highly mechanized mother ships of 43,000 tons displacement. Some of the larger carry a crew of 300 men, have a cruising range up to 12,000 miles, and can be absent from port for 6 months.

Factory or mother ships are now operated in most of the great fisheries of the world. Their exploits now make local fishery problems international problems. They are most prominent in the whale fishery of the Antarctic, being utilized to render oil, and sometimes meal, from the whale carcass. They are used also in the salmon and crab fisheries of the Pacific for canning and in the tuna fishery for freezing. Until recently they have been utilized in the pilchard fishery off the Pacific Coast states to manufacture meal and oil. Recent state laws, however, have prevented this and now most of the pilchard factory ships operate at piers as land stations. One former pilchard factory ship is now operating in the herring fishery off Newfoundland. From time to time fish-freezing ships have operated in the North Atlantic, and during the past several years American and Japanese shrimp-freezing ships have operated off Mexico. A recent report from Sydney, Australia, indicates that a fishery firm there is importing a trawler with equipment for quick-freezing fish at sea. Other instances could be cited, indicating that the factory ship is becoming more and more important in the prosecution of the world's fisheries.

Being mobile and highly versatile units, factory ships can prosecute a fishery in almost any sea of the globe, following the schools or runs of fish for thousands of miles throughout their entire range. These ships have been of great value as a tool in securing food and products of use in the arts and industries. They also have been most useful in creating employment and furthering trade and commerce. But it is questionable whether the unrestricted operations of these vessels will contribute to the conservation of the world's fish supply if they are permitted to exploit at will a fishery new to their flag and one which is already exploited by fishermen of another nation or nations.

In this connection it should be observed that the days of discovery of territory and fisheries are about over. Land along the sea and on the islands in the sea has been fairly well occupied. The world's fishery resources have been fairly well charted, and in general somewhat intensively prosecuted by neighboring countries. The strain to which these resources can be subjected by man's fishing activities alone remains to be determined, although with some fisheries, notably the eastern North Pacific halibut fishery, this also is known.

The fisheries of the Americas have been developed and conserved by American initiative at American expense. Huge sums have been expended for vessels, fishing gear, and equipment to prosecute these fisheries. Additional sums have been expended for shore processing plants, warehouses, transportation systems, and the like to handle and market the finished product. Fishing villages have grown to cities, their very economic life now depending upon continuance of neighboring fisheries. Millions of dollars have been spent by American governments to conserve and sustain these fisheries. That a commendable conservation job has been done is evidenced by the sustained yields of American fisheries. Notable examples are the fisheries for salmon and halibut in the Pacific. The richness of these fisheries, which have long been prosecuted commercially by contiguous countries, is now attracting the attention of other countries not heretofore interested in them. It appears, however, that the propinquity of these fisheries to the geographical position and environment of the Americas demands that they remain with the American people, whether prosecuted along the inshore waters or on the high seas contiguous to American territory.

In regard to fisheries on the high seas, there has recently been discussion of whether any nation or group of nations has exclusive rights over fisheries prosecuted on the high seas by their nationals. Some have held that the high seas fisheries are international in scope, and therefore are not subject to control by any particular nation or nations. Such a presumption presupposes that if two countries which have long and continuously occupied and developed a fishery decide, in an effort to conserve and sustain it, to adopt certain regulatory measures toward this end, the fishermen of a third country can step in, claim a portion of the resource, and prosecute the fishery free from any restrictions whatsoever. Practice under such a theory would disrupt the economic and biologic balance of any fishery. Eventually it would lead to its complete destruction.

It is my belief that international law with respect to rights on the high seas was intended to cover primarily such matters as shipping, customs, defense, immigration, health, and the like. In all these some manmade situation or thing is concerned. The situation with respect to sea fisheries is different. Fish recognize no political boundaries. They are found along shore and on the high seas. Some inhabit the surface, some the bottom. Some spawn on the high seas and others in shallow water along shore. Some that live in the sea spawn in the rivers and some that live in the rivers spawn in the sea. Some, of migratory character, have a wide range, and at times of the year they may frequent waters off the coasts of two or more countries. All the king's horses and all the king's men cannot change their mode of life and environment—except that man and his machines can deplete their stocks by overfishing.

It seems, therefore, that we cannot consider the international aspect of the sea fisheries on the same basis as shipping, customs, and the like. First of all, we must review the problem in the light of the life history of the fish as it lives in the sea—its spawning habits, food, growth, migrations, and other biological factors. Such a review will reveal the need for adopting measures for the wise prosecution of many fisheries. Such a review also will reveal that there is a limit to which a fishery can be strained. Such a review further will reveal the need for arriving at some policy for the prosecution of the important fisheries of the world. It is of moment that such a policy be outlined at an early date, lest the unrestricted operations of the factory ship, a type of ship which is assuming a permanent rôle as a fishing tool, results in complete unbalance of the world's fisheries.

Second, we must review the situation with respect to manmade conditions and the economic significance of the fishery in order to evaluate the extent of control a country or countries may have over certain fisheries. Such a review could well be based on the following points:

a) Prior occupation of the fishery.
b) Continuity with which the fishery has been prosecuted commercially.
c) Efforts to develop, promote, conserve, and sustain the fishery.
d) Geographical position of the fishery in relation to neighboring countries.
e) Economic importance of the fishery to countries involved.

An evaluation of the fisheries contiguous to the Americas, in the light of biological dictum and the points just listed, indicates that these fisheries may properly be considered an American resource subject to protection and regulation by the American coastal states. In line with this, and to formulate a basis upon which to effect the wise prosecution of these American fisheries, I make the personal suggestion that the governments of the coastal states of North and South America take the position that henceforth the fisheries contiguous to the Americas are not to be considered as subjects for future unregulated exploitation by fishing vessels from overseas.

Having thus established the metes and bounds of American fisheries, interested American coastal states then could promulgate a program for the conservation and sustained production of these fisheries throughout their entire range off the Americas. Toward this end it is suggested further that a committee of experts could be chosen by the respective interested American governments that would meet in conference to develop a program for inter-American fishery coöperation for presentation to their respective governments. This suggestion, while more limited in its scope, is in accord with that of M. José León Suárez of Argentina as mentioned in his report, under date of December 8, 1925, to the Committee of Experts for the Progressive Codification of International Law. M. Suárez suggested convening a special technical conference of all maritime powers to draw up uniform regulations for the exploitation of the industries of the sea over the whole extent of the ocean bed forming part of the continental shelf. His suggestion was not acted upon by the Committee. It is believed, however, that a conference of American experts would meet with accord in American fishery circles, as is indicated by the remarks of M. Luciano H. Valette, chief of the Fisheries Department of the Argentine Ministry of Agriculture, in commenting on the proposal of M. Suárez. In his remarks M. Valette expressed the hope that the proposal of M. Suárez would at least "triumph in the narrower but more congenial sphere of American interests."

In conclusion I wish to state that I have attempted to outline and discuss the problem raised by the exploits of the factory ship in the light of economic and biologic dictum. The international aspects of the problem, of course, are a matter for handling by the State Department.

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THE PRESERVATION OF TUNA BY CHILLED BRINES: A PROGRESS REPORT

By O. W. Lang and Lionel Farber

(A contribution from the George Williams Hooper Foundation for Medical Research, San Francisco, California)

The study of measures to be taken for the adequate preservation of tuna after capture at sea must necessarily lead to investigations on the most efficient means of heat exchange between the fish and the cooling medium. The necessity for the study is apparent when the conditions under which the high seas fleet operates are known.

The tuna fleet in its quest for fish often travels from 2000 to 8000 and even 10,000 miles in the course of one cruise and it may be at sea or away from the home port from 21 to 100 or more days. Tuna may be captured in waters whose temperature varies from 60° to 62° F. in one region of the Galápagos Islands to from 80° to 88° F. along the coast of lower Mexico southward to Panama. On one side of the Galápagos Islands the water temperature may approach 62° F., while on the other an increase to 84° or 86° F. may be observed. The lower temperatures are the exception and not the rule and it may generally be said that the majority of yellowfin tuna are captured in waters whose temperature ranges from 84° to 88° F., with perhaps 90° F. as an upper limit.

Where the cruises are long, tuna may be shipped from some Central American port by coastwise steamer. In this connection it may be of interest to note that one of the authors has just recently completed an 88-day voyage on board one of the tuna clippers, in which 79 days were spent at sea and during which none of the cargo was shipped. The oldest fish delivered in ideal condition for canning were 73 days old. These fish were caught in waters whose temperature ranged from 82° to 86° F. The temperature of storage ranged from 0° to —10° F.

Briefly, with these conditions in mind, and from an economic standpoint, all practical and possible available space must be utilized for the stowage of cargo and for refrigeration. Moreover, where the fish are stowed more or less compactly into holds, refrigeration through convection currents affords an ideal means of heat exchange with chilled sea water followed by low temperature dense sodium chloride brine solutions as the cooling mediums. The value of any system of refrigeration depends not alone upon the maintenance of a satisfactory state of preservation, but also upon the quality and marketability of the final product. With these two factors as guides, a series of experiments were carried out to determine the optimum and limiting factors concerned in brine refrigeration. The topics for discussion in this connection are salt infiltration, state of preservation of the fish for various storage periods at their respective temperatures, and finally the influence of these two factors upon the quality of the final product.

Salt infiltration.—A review of the literature on the rate and extent of salt infiltration into fish flesh under various conditions is restricted to relatively small fish when compared to tuna. This work was performed by Plank and his associates, Schmidt-Nielsen, the Food Investigation Board of Great Britain, and Almy and Field (see References below). These investigators dealt generally with short time intervals of immersion, when little if any of their investigations could be applied directly to the specific situation which confronts the tuna industry.

Local bluefin tuna weighing 18 to 30 pounds formed the basis for the first several series of experiments. These were immersed into warm and precooled still sodium chloride brines in which the storage temperatures were held approximately 2° F. (1° C.) above the freezing points of their respective concentrations. The brine concentrations used at their respective storage temperatures are as follows:

Brine concentration	Storage temperature	
3 per cent	30° F.	− 1°11 C.
10 per cent	22° F.	− 5°56 C.
17 per cent	8° F.	−13°33 C.
23 per cent	− 5° F.	−20°56 C.

Cooling rates for each experiment were determined by inserting thermocouples into the fish to the back bone, the point of insertion being adjacent to the first dorsal fin. The temperature of the cooling medium was also determined by thermocouples wrapped around the fish. The cooling rates are presented in figure 1.

One fish from each set was removed at progressive storage intervals, rinsed, and sampled for salt infiltration, in which process the skin and three successive quarter-inch slices of flesh were taken for analysis. These analyses were carried out in the usual manner, the sample being dried to constant weight in a previously tared crucible, ashed, and reweighed. The ash was extracted with 5 cc. of 10 per cent by volume acetic acid and a sufficient quantity of distilled water to bring the volume to 50 cc. The sodium chloride in a 5-cc. or 10-cc. aliquot was determined by direct titration with 0.2N silver nitrate solution, using potassium chromate as the indicator.

Curves correlating percentages of salt and time were drawn for each concentration of the warm and precooled sets of brine experiments. The maximum percentage of increase of sodium chloride per day for each sample was determined by calculating the slope of the steepest portion of the curve. These data are shown in table 1. In table 2 is given the final concentration of sodium chlo-

TABLE 1

PENETRATION OF SALT INTO BLUEFIN TUNA FROM BRINES AT VARIOUS TEMPERATURES

Brine conc., per cent	Temperature		Maximum percentage of increase in salt per day in			
	° F.	° C.	Skin	1st ¼-in. flesh	2d ¼-in. flesh	3d ¼-in. flesh
			Warm			
3.5	30	− 1.11	0.323	0.347	0.0957	0.0633
10	22	− 5.56	0.356	0.463	0.275	0.0757
17	8	−13.33	0.755	0.728	0.161	0.0235
23	−5	−20.56	0.593	0.342	0.0383	0
			Precooled			
3.5	30	− 1.11	0.0938	0.124	0.0407	0.0567
10	22	− 5.56	0.418	0.530	0.1085	0.0359
17	8	−13.33	0.644	0.234	0.1083	0.0332
23	−5	−20.56	0.339	0.182	0.0325	0.00475

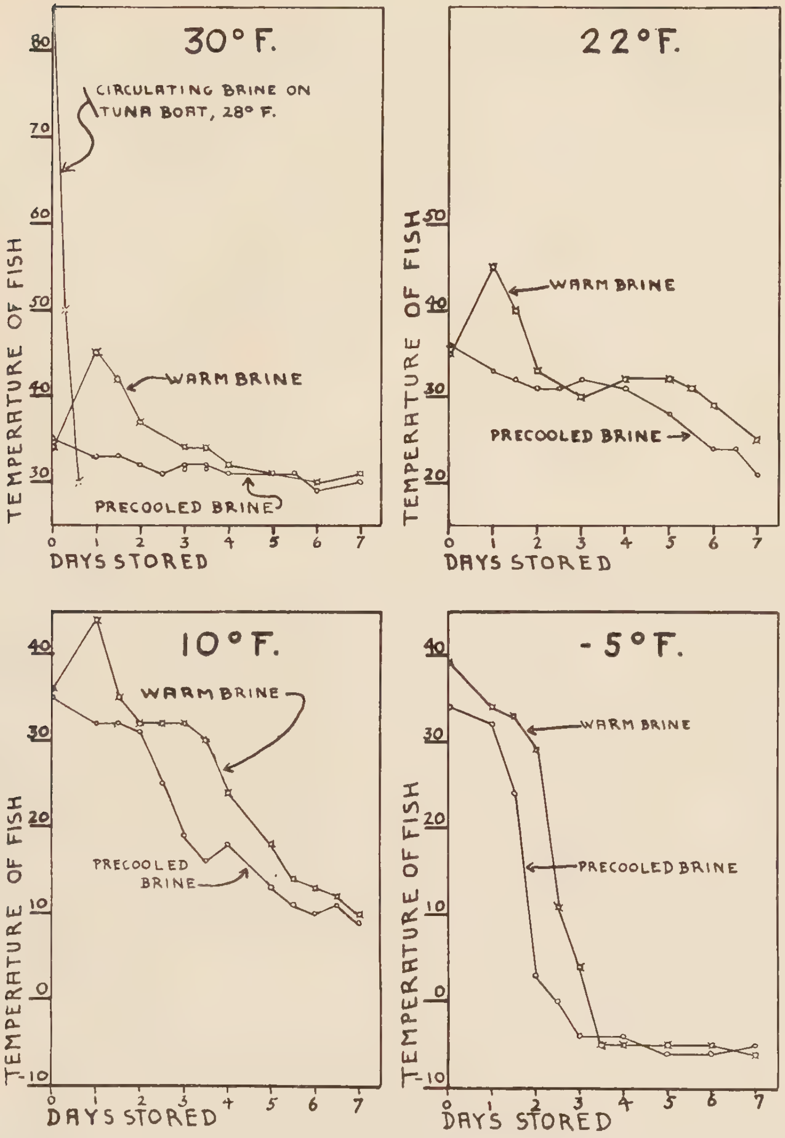


Fig. 1. Rates of cooling of tuna immersed in warm and precooled still sodium chloride brines at various temperatures, as well as of tuna in circulating brine on board a commercial tuna clipper.

ride in the fish after storage periods of 48 days for those in 3-per cent brine, and of 56 and 57 days for the remainder of the warm and precooled fish respectively.

The studies just described were supplemented by experiments conducted directly on a recently constructed tuna boat equipped with advanced methods for refrigeration.

The cruise extended into southern waters and the fish caught with the usual commercial methods were yellowfin tuna. These were stowed in wells main-

TABLE 2

Sodium Chloride in Tuna after Storage in Brines

Storage temp.		Brine percentage	Percentage of sodium chloride in			
° F.	° C.		Skin	1st ¼-in. flesh	2d ¼-in. flesh	3d ¼-in. flesh
30	− 1.11	3 Warm	2.20	2.86	2.35	1.78
		Precooled	2.40	2.40	1.96	1.44
22	− 5.56	10 Warm	5.65	6.92	5.11	1.81
		Precooled	5.27	6.56	4.08	0.99
8	−13.33	17 Warm	4.71	8.60	2.90	0.37
		Precooled	5.75	8.10	2.71	0.36
−5	−20.56	23 Warm	9.22	4.04	0.23	0.04
		Precooled	7.90	7.36	0.46	0.08

tained at different temperatures. As in the previous experiment, thermocouples were inserted into the fish, with the control couple wrapped around the body to determine the rate of freezing in the densest portion as well as the temperature of the cooling medium. As will be outlined later, the fish were immersed directly into sea water prechilled to temperatures approximating 28° to 30° F. The fish remained at these temperatures either until the well had been filled or until a convenient time had elapsed when further freezing could be supplemented with precooled dense brine.

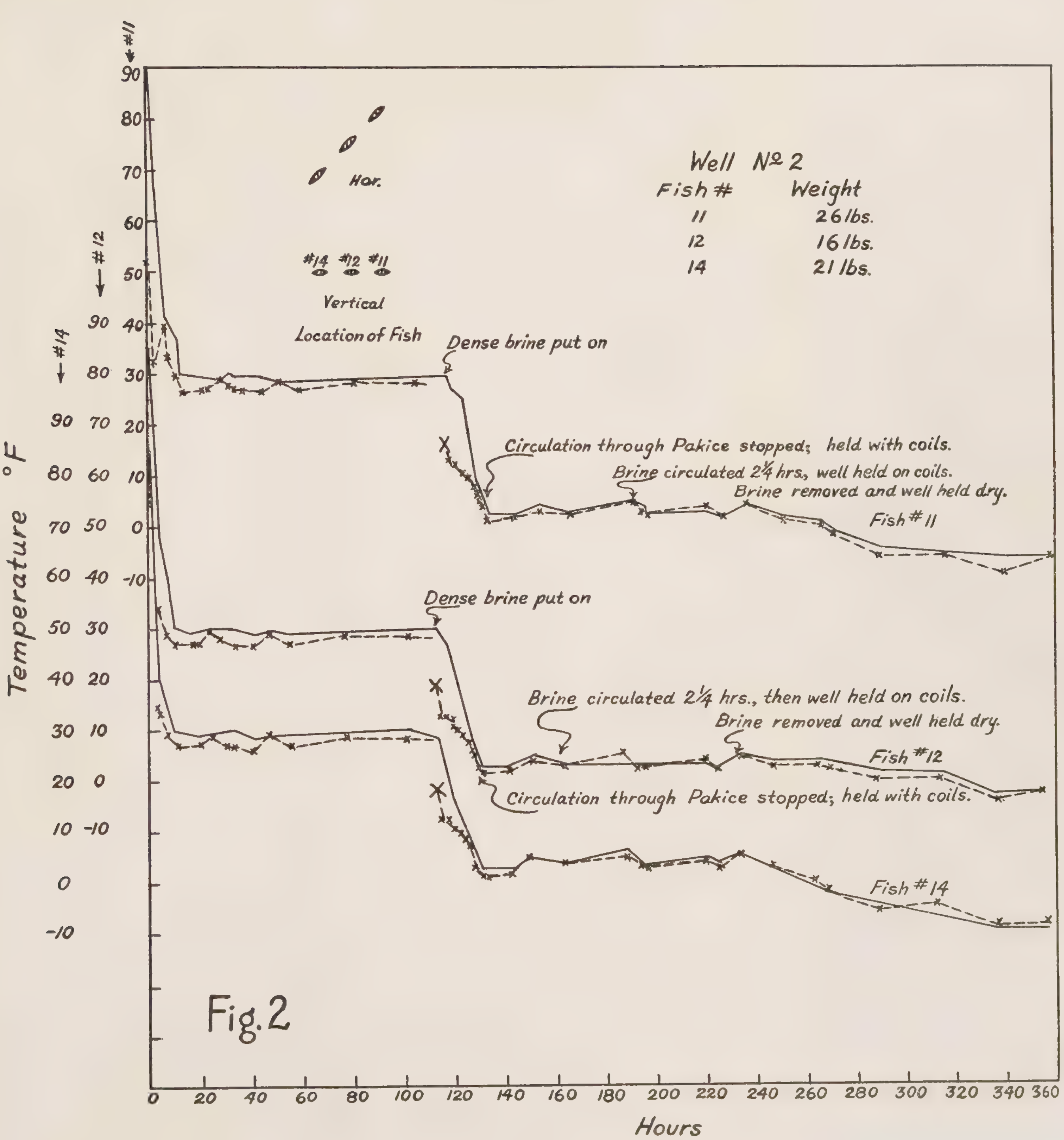
As can be seen from figures 2, 3, and 4 the cooling rates from sea-water temperature to 30° F. approximated 10 hours. An additional 10 to 12 hours was then required to freeze the fish from 30° F. to the respective storage temperature. From wells 2, 5, and 7 the dense brine was later removed, and the wells were thenceforth held dry, refrigeration being supplemented by the ammonia coils. The fish in well 11 were immersed into a mixture of dense brine and slush ice in which the temperature was maintained at approximately 22°.5 F. The salt infiltrations to various depths are presented in table 3, in which the salt values represent the averages of five fish.

Discussion on salt infiltration.—The two experiments as outlined represent extremes in refrigerating conditions. Obviously in the still brines the slowest

TABLE 3

Percentage of Sodium Chloride in Yellowfin Tuna Stored on Board a Tuna Clipper

Well number	Hours at 30° F.	Final storage conditions	Percentage of sodium chloride in			
			Skin	1st ¼-in. flesh	2d ¼-in. flesh	3d ¼-in. flesh
1	100	Dense brine, −5°F.	4.97	1.35	0.56	0.17
2	103	Dry, on coils, −5° F.	3.33	1.54	0.49	0.08
3	98	Dense brine, 5° to 10° F.	5.03	2.84	0.71	0.13
5	0	Dry, on coils, 15° to 20° F.	5.76	0.25	0.08	0.13
7	0	Dry, on coils, −5° F.	3.64	0.57	0.43	0.14
11	20	Dense brine and slush ice, 22.5° to 25° F.	5.01	3.23	0.82	0.06



#11
#12
#14
Temperature °F
90
80
70
60
50
40
30
20
10
0
-10
Hor.
#14 #12 #11
Vertical
Location of Fish
Well № 2
Fish # Weight
11 26 lbs.
12 16 lbs.
14 21 lbs.
Dense brine put on
Circulation through Pakice stopped; held with coils.
Brine circulated 2¼ hrs., well held on coils.
Brine removed and well held dry.
Fish #11
Dense brine put on
Brine circulated 2¼ hrs., then well held on coils.
Brine removed and well held dry.
Fish #12
Circulation through Pakice stopped; held with coils.
Fish #14
Fig. 2
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
360
Hours

Figure 2.

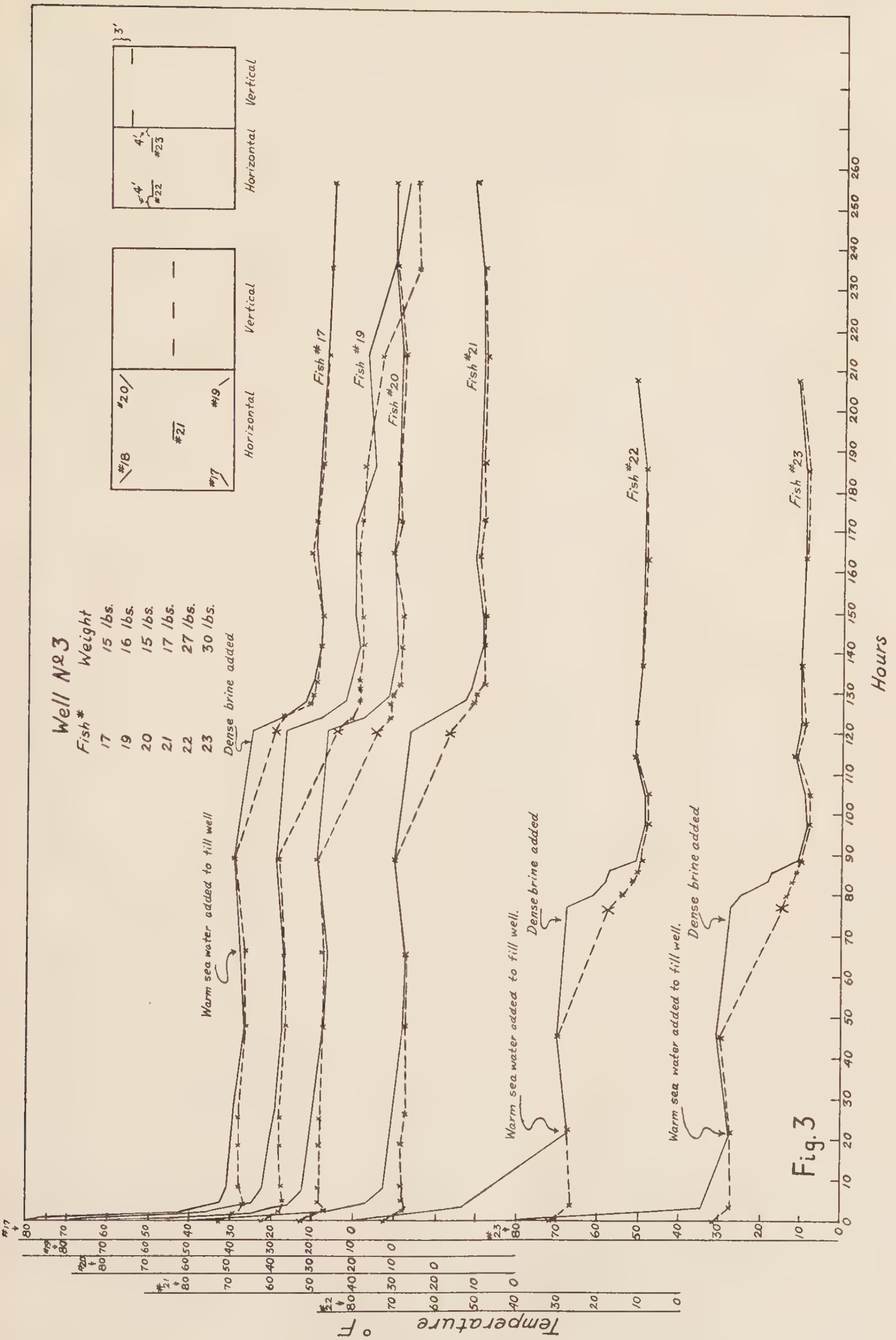

Well No 3
Fish #
Weight
17 15 lbs.
19 16 lbs.
20 15 lbs.
21 17 lbs.
22 27 lbs.
23 30 lbs.
Dense brine added
Warm sea water added to fill well
Fish #17
Fish #19
Fish #20
Fish #21
Fish #22
Fish #23
Warm sea water added to fill well.
Dense brine added
Warm sea water added to fill well.
Dense brine added
#18
#20
#21
#17
#19
Horizontal
Vertical
4'
#22
4'
#23
3'
Horizontal
Vertical
Hours
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200 210 220 230 240 250 260
Fig. 3
Temperature °F
#17 80 70 60 50 40 30 20 10 0
#19 80 70 60 50 40 30 20 10 0
#20 80 70 60 50 40 30 20 10 0
#21 80 70 60 50 40 30 20 10 0
#23 80 70 60 50 40 30 20 10 0
#22 80 70 60 50 40 30 20 10 0

Figure 3.

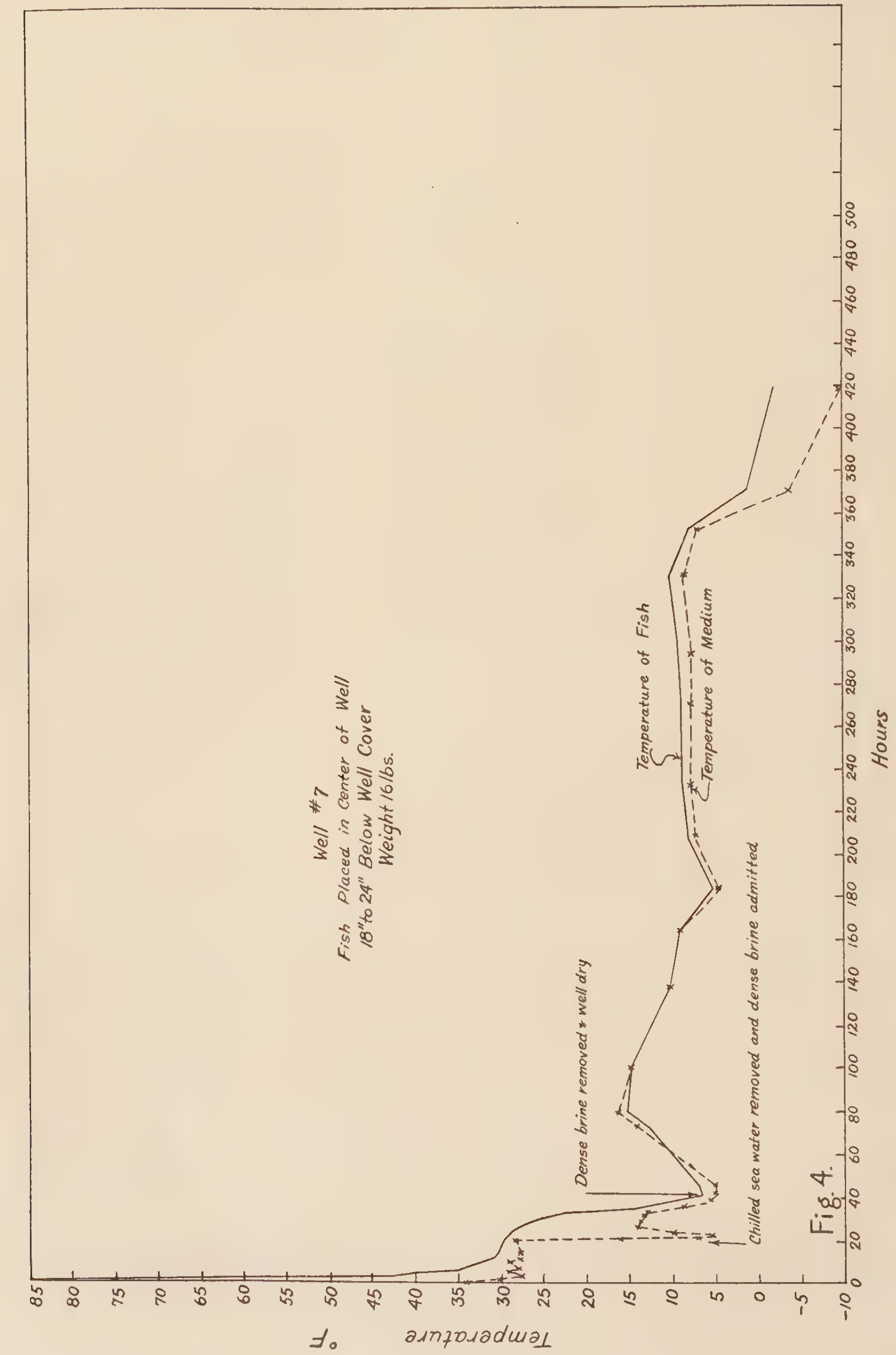

Well #7
Fish Placed in Center of Well
18" to 24" Below Well Cover
Weight 16 lbs.
Dense brine removed + well dry
Chilled sea water removed and dense brine admitted
Temperature of Fish
Temperature of Medium
Fig. 4.
Temperature °F
Hours
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
-5
-10
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
360
380
400
420
440
460
480
500

Figure 4.

rates of freezing as well as the upper limits where spoilage would occur were desired. It is obvious that the salt content in such forms of freezing is materially higher than in fish refrigerated under forced convection. As one would expect, salt penetration is greatest where fish and brines were chilled simultaneously. The salt penetration is also relatively high where fish are immersed into precooled still brines and then chilled to their respective holding temperatures. The results obtained in this latter experiment show that the salt content is so high that little or no advantage could be gained in practical application. The penetration of salt past the first half-inch of flesh, however, was practically insignificant even in the most severe conditions of refrigeration and for the fish in 23 per cent brine at —5° F. the first quarter-inch of flesh was the limit of salt infiltration. These observations are clearly connected with the rate of chilling of the outer layers of flesh. The data presented from the experiments conducted directly on the tuna boat exemplify this contention. The rapid chilling of fish from their high initial temperatures to 30° F., followed by their subsequent storage in low-temperature dense brines, resulted in a much lower salt content in the flesh than that of fish cooled more slowly in the still brines. The salt infiltration takes place to its greatest extent while the fish are being chilled from their initial temperature to 30° F., and after the outer layers of flesh are once chilled the salt penetration at lower temperatures is practically insignificant.

In conjunction with the prechilling of fish to 30° F. in precooled sea water a series of experiments was conducted in which the fish were immersed directly into precooled dense brines at 10° F. and the brine held at this temperature. Analyses of fish so treated show that the skin had a salt content of 7.77 per cent; the first quarter-inch, 4.35 per cent; the second quarter-inch, 3.36 per cent; and the third quarter-inch, 0.23 per cent. As can be seen, these values are appreciably higher than those in fish that were first chilled in sea water and then frozen in dense brine. The fish in wells 5 and 7, which were frozen more rapidly than those in other wells, contained no more salt in the first quarter-inch of flesh than the freshly caught fish. On the other hand, the fish stored in well 11 that were held at 22.5° F. in dense brine and slush ice contained the greatest amount of salt in the first quarter-inch of flesh of any of the commercially stored fish, which nevertheless is considerably lower than that in fish held in 23 per cent still brine.

As a summary, it may be stated that salt infiltration is an inverse function of the rate of freezing, or that the more rapidly the outer layers of fish are chilled the smaller will be the amount of salt entering the flesh. Where fish are immersed directly into dense brine the greatest infiltration of salt takes place during the chilling process from the sea-water temperature to 28° F.

Studies in preservation.—The efficacy of various methods for the determination of decomposition was investigated. Some of the results are given briefly from a comparative standpoint only. Determinations were made for total volatile nitrogen, trimethylamine, volatile acids, protein nitrogen, carbonyl compounds, iodine-consuming compounds, and indole. These methods were used in connection with the raw fish, the fish after precooking, and the final canned product. The volatile substances emanating from the precookers were also studied.

It is not within the scope of this paper to discuss the relative merits of these different methods as a means for determining spoilage, and for the sake of brevity most of this information is omitted. Suffice it to say, however, that fish stored at 30° F. in a 3 per cent still brine showed definite indications of spoilage within seven days in both the warm and the precooled series. The amounts of trimethylamine observed at this time were at their maximum although the experiment was continued for a period of 48 days. On the other hand, no spoilage was observed in fish stored for fourteen days in chilled sea water where the temperature range at all times remained between 28° and 30° F. and where the sea water was kept in constant motion at the rate of 550 gallons per minute. Indications of spoilage were observed after twenty-one days' storage in still brines where the temperature was maintained at 22° F. Definite spoilage was observed after thirty days' storage. No indications of spoilage were observed in fish stored in dense brines at 10° and — 5° F. after a maximum storage period of 150 days. This includes both the fish immersed in still brines and those refrigerated at the same temperature under commercial conditions on a tuna boat.

Bacteriological counts were made on the brines at the various temperatures and it may be of interest to note here that the values observed followed closely the relationship established by chemical examinations. Fish stored at 30° F. in still brine showed a bacterial rise of 37,000 organisms per cc. after two days; after seven days, 900,000 organisms; and after twenty days, a count considerably above 2,000,000. An original count of the order of 2000 organisms per cc. was observed in all concentrations of brines stored at their respective temperatures. The brines stored at 22° F. showed a rise of 7000 organisms per cc. after twenty days' storage and 11,000 organisms per cc. after thirty days. The brines stored at 10° F. and — 5° F. remained relatively constant up to seven days, following which a definite drop from 2000 organisms per cc. to 700 organisms per cc. was observed.

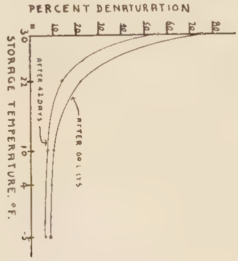


Fig. 5. Denaturation of proteins of tuna muscle press juice on storage at various temperatures.

Studies in quality.—The effect of the various methods for brine chilling and subsequent storage of the raw fish in connection with quality may now be considered. The changes occurring in fish muscle at the various storage temperatures, as has been pointed out by Reay, Finn, and others, is of vital importance from a quality standpoint. The formation of drip, according to Reay, occurs mainly at temperatures ranging between 30° and 26° F. The rates of freezing and thawing influence the loss of soluble constituents of the flesh in the same manner. An increase in rate in either case results in a decrease in the loss of soluble constituents. Reay furthermore pointed out that the amount of change of various kinds brought about by freezing is largely dependent upon the time of cooling within the maximal zone of change, namely, between 30° and 23° F., this influence being exerted between any complete temperature-time cycle.

Similar observations have been noted for tuna muscle stored at various temperatures, as can be observed in figure 5. Protein denaturation is at a maximum at 30° F. The amount of denaturation drops rapidly until a certain constancy is reached at 10° F. It will be noted here that no appreciable change in values appears at temperatures ranging between —5° and 10° F.

Conclusions.—In conclusion it may be said that the rate of chilling to 30° F. is a very definite factor in fish preservation. For practical purposes all tuna boats, considering the length of time at sea, should store their fish at temperatures ranging from — 5° to 10° F., with 10° F. as an upper limit. Temperature fluctuations should be maintained at a minimum and the fish chilling from atmospheric temperature to 30° F. as well as the subsequent freezing in dense brine should take place as rapidly as possible. The rate of salt infiltration, subsequent color, flavor, and texture of the final product will be markedly influenced by variations in these conditions.

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THE CHEMISTRY OF MARINE MAMMAL, FISH, AND FISH-LIVER OILS AS RELATED TO THEIR UTILIZATION IN WORLD COMMERCE

By H. N. Brocklesby

Owing in part to the interchangeability of various kinds of fats and oils for food and industrial purposes brought about by modern processing developments, and in part to the very large production of whale oil, this latter commodity has a very definite bearing on world prices of fats and oils. During the 1937–38 season whale-oil production totaled about 590,000 tons, but the purchase by the British Government of about 135,000 tons as a reserve food supply and the very large importations by Germany left only a small balance of this production. The production for the current season is only about 20,000 tons less than last year. Exact figures for the world production of fish oils are hard to obtain, but it would appear that they average about 350,000 tons a year. Oils from all marine animals are therefore a very important factor in world commerce.

Sources of Marine Animal Oils

Marine animal oils of commercial importance are obtained from two large biological groups, marine mammals (the Cetaceans) and the fishes. In the former group most of the body fat is contained in the blubber or fatty layer under the skin. In addition, the sperm whale (Physeteridae) contains considerable amounts of oil in certain cavities in the head. In porpoises and dolphins (Delphinidae) the jaw and head also contain oil, the composition and properties of which differ from those of the blubber oil. Livers of marine mammals, like those of terrestrial mammals, contain but little fat or oil.

From the fishes, fat may be obtained from the thin adipose tissue beneath the skin, muscular and connective tissue, liver, eggs, and various parts of the intestine. The commercial fish oils are usually derived from the whole fish (body oils) or from the liver only.

In the Teleostomi the chief fat depots may be either the muscular tissue —as, for example, in salmon and herring—liver, or even parts of the intestine. As a general rule, fish with high muscular fat content have relatively nonoily livers, while those in which the liver is the main storage depot have relatively small amounts of oil or fat in the muscular tissue. In the Elasmobranchii the liver is the main fat-storage depot, but the muscular tissue may also contain considerable fat.

Chief Localities of Production

Whale, fish, and fish-liver oils are products of all five oceans. For whale oil the whaling grounds of the south Antarctic are the most important, as they produce 80 per cent of the world's supply of this oil. The rest is produced in the following areas: South Georgia, 4.5 per cent; west coast of Australia (Indian Ocean), 4.5 per cent; South African coast, 4.5 per cent; North Atlantic and Arctic oceans, 0.6 per cent; South Pacific, 2.5 per cent; and North Pacific, about 3 per cent.

The world's supply of fish oils other than medicinal liver oils is made up principally of sardine (pilchard), herring, menhaden, salmon, cod oil, and various less important oils from miscellaneous species. They are produced chiefly in the following areas: *sardine,* the Pacific coast of North America from southern California to British Columbia, the Pacific coast of Japan from the Bay of Osumi to Cape Yerimo, the Japanese Sea along the west coast of Hokkaidô and the east coast of Chosen, and to a small degree in the Bay of

Bengal off the coast of the Madras Presidency, India; *herring*, the Pacific coast of North America from British Columbia to Alaska, the Pacific coast of Japan particularly in the vicinity of Cape Yerimo, the Atlantic and Arctic oceans chiefly along the northwest coast of Norway and around Iceland and to a lesser degree the North Sea and the Atlantic coast of North America; *menhaden*, the Atlantic coast of North America; *salmon*, as a by-product of salmon canneries, on the Pacific Coast of North America from Washington to Alaska and the Pacific coast of Asia off Kamchatka; *cod oil*, a by-product of the cod-liver oil industry, chiefly in the North Atlantic off the Lofoten Islands, Faroë Islands, Westman Islands, and the Grand Banks off Newfoundland. Smaller quantities of fish-body and liver oils are produced in a large number of localities throughout the world, but the total volume of these oils is relatively small.

Methods of Production

During the past few years, machinery and equipment for the production have been developed to an appreciable degree. Naturally the objective has been more efficient and economical methods and the maintenance of a product of uniformly high quality. In the whale-oil industry the chief developments have been in the pelagic whaling factories. The factory ships that accompany the whalers are now equipped with the most modern machinery, the open rendering tanks having been replaced by automatic continuous or semicontinuous pressure cookers that render the blubber in from a half to a quarter of the time required by the old-type equipment. New developments in disintegrating machinery allow the blubber to flow into the pressure cookers in the form of a semiliquid brei in which form rendering is much more quickly and efficiently carried out than when in the form of blocks as produced by the older hacking machines. The oil, after separation from the blubber, is dried and polished by passage through specially designed filters and highly efficient centrifuges. Gravity settling tanks have been in large part replaced and the finished product, once separated from the blubber, is pumped to the storage tanks in a few minutes.

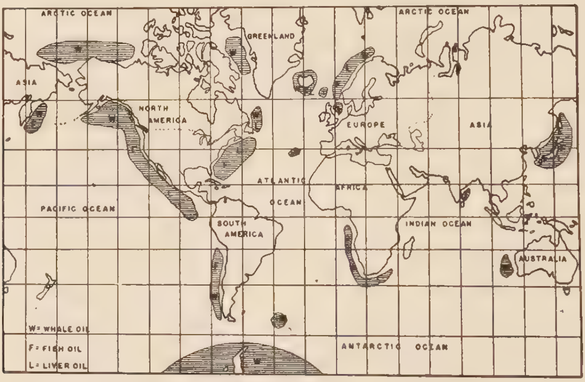

Fig. 1. World distribution of fish-oil production.

Fish-oil production is now accomplished, for the most part, by the continuous steam cooking and pressing of the whole fish (or, sometimes, offal or trimmings from canneries, etc.), followed by the centrifugal separation of the oil from the press liquor. Recent developments in this field have been directed toward high capacity centrifugal separation of oil from the press liquor and chemical treatment of the fish, both before and after cooking, in order to reduce the oil content of the fish meal and to facilitate removal of oil from the liquor. In both directions appreciable successes have been achieved and the modern fish-meal and oil plant can be said to be very efficient so far as oil yields are concerned. A problem that has bothered the industry for some time is that of the processing of raw materials which, owing to stormy weather or other unforeseen circumstances, have become soft and stale before arrival at the plant, but this phase of production has been assisted somewhat by recent developments in chemical bactericidal agents that can be used economically on raw fish even when the latter are processed in very large quantities.

World Trade in Marine Animal Oils

In table 1 some data on the world trade in marine animal oils are given. These data, although compiled from the most reliable sources available, are intended only as an indication of the volume and direction of movement of these oils, since accurate and detailed statistics from certain countries are not obtainable. The demand for whale and fish oils in any country is intimately related to the availability of other fats and oils and also to the political and/or economic situation. Norway and Japan are the two greatest producers and exporters of marine animal oils. Norway has but a small domestic consumption and exports most of her cod-liver, whale, and herring oils, the latter two either in the raw condition or as the refined and hydrogenated product. Japan, on the other hand, relies noticeably upon whale and fish oils for her fat requirements; but the very great production of sardine oil and low costs of hydrogenation enable that nation to export rather large amounts of the raw and hydrogenated product, even to countries which themselves produce these commodities. Great Britain and Germany are the two countries with the largest imports. The former imports not only raw whale oil, but also hydrogenated whale and fish oils; her reëxports are small. German imports are for the most part raw whale and fish oils; all refining and hydrogenating are done domestically and her exports are practically nil. The United States and Canada produce more fish oil than whale oil. The former country consumes practically all its production within its own borders and in addition imports large quantities of medicinal liver oils and commercial cod oils, chiefly from Norway and Newfoundland. Canada exports the larger amount of her fish-oil production and in turn imports cod-liver oil. The Netherlands trade in whale and fish oil is chiefly concerned with the importation of raw oils and the exportation of the hydrogenated product, the chief market being in Great Britain and to a lesser degree in central European countries. Newfoundland exports almost all her production of cod-liver oil, commercial cod oil, and whale oil, her chief markets being in Great Britain, the United States, and Canada. The writer has not seen any reliable data from Russia, but judging from the number and nature of the scientific publications in the field of the utilization of fish oils, one would surmise that sizeable quantities are used domestically. The production and consumption of fish oils in South American countries are very small since these countries themselves produce and export vegetable and animal oils. The same is true in some degree of Australia and New Zealand, although the latter country now operates a whaling fleet that exports the products of its catch to Great Britain. The remaining countries of the world are either well supplied with vegetable and animal fats and oils or are small importers of whale and fish-oil products.

TABLE 1

World Trade in Marine Animal Oils in Tons for the Year 1937

Country	Production			Import			Export		
	Whale	Fish	Liver	Whale	Fish	Liver	Whale	Fish	Liver
United Kingdom	1937–38 season 140,000	1,000	(C.L.O.) 20,000	137,000	45,000	(C.L.O.) 1,263	4,000	3,500	(C.L.O.) 6,800
Canada	3,015	15,130	125	153	197	(C.L.O.) 1,731	2,438	10,204	(C.L.O.) 186
Germany	101,000	....	....	(W. and F. oil) 186,230		....	(W. and F. oil) 7,502		......
Netherlands (Holland)	54,889	....	....	32,500	3,710 (Cod)	1,107	(W. and F. oil hyd.) 53,853		166
United States	30,000	100,000	(C.L.O.) 1,000	....	11,000	28,000	....	1,000	......
Japan	66,000	160,000	....	....	....	....	10,000	50,000	......
France	....	....	....	590	1,400	1,100	....	....	......
Newfoundland	....	....	....	....	....	....	5,843	....	3,546
South Africa	24,303	....	....	(W. and F. oil) 218		....	3,000	....	......
Australia	....	....	....	221	7,300	....	....	....	......
Cuba and South America	11,266	Sm. amt.	....	....	2,730	1,100	....	....	......
Norway	186,107	....	....	....	....	....	....	....	......
New Zealand	13,212	....	....	....	....	....	....	....	......
India	....	2,000	....	(W. and F. oil) 550		....	....	....	......

Composition and Chemical Properties of Marine Animal Oils

The methods used for determination of the composition of the fatty acids of oils and fats give data on the distribution of the acids according to the number of carbon atoms, but, for unsaturated acids, merely report the average unsaturation. Little information is therefore available on the actual amounts and, more important still, the actual structure of the unsaturated acids that form the chief constituents of marine animal oils. However, the methyl ester method of fractionation does show some striking differences between the compositions of some of the various marine animal oils of commercial importance. In table 2 are given some compositions of a few representative oils. In the saturated acids palmitic (C_{16}) is the most characteristic, smaller amounts of C_{14}, C_{18}, and C_{20} being found. In the unsaturated acids the range extends from C_{14} to C_{24}, the higher members usually being very highly unsaturated. In the Teleostomi little difference is to be noted between the compositions of the body oils such as those of the Clupeidae and the liver oils of the Gadidae, with the exception of the range of unsaturation (expressed in the table in terms of lack of hydrogen, — H), which is definitely higher in body oils than in the liver oils. Another lesser difference is in the total amount of saturated fatty acids, which is usually lower in liver oils than in body oils. These differences are hardly enough to explain the dissimilar chemical properties and it must be concluded that the unsaturated acids in the body oils have structures different from those in liver oils.

In the Elasmobranchii a change in fatty acid composition is noticed with varying amounts of unsaponifiable matters. In the liver oils having low unsaponifiable contents the fatty acid composition is similar to that of the liver oils of the Gadidae, with the possible exception that the former are more highly unsaturated in the higher carbon groups. When large amounts of unsaponifiable matter are present, however, the total unsaturation of all the unsaturated acids rarely exceeds — 2H and considerable quantities of mono-ethylenic C_{24} acids make their appearance. Liver oils of this group with unsaponifiable matters between the two extremes given in the table have intermediate fatty acid compositions.

In the Cetacea some characteristic compositions are to be noted. In the Balaenidae the blubber oil is characterized by a large amount of mono-ethylenic C_{18} fatty acids and relatively smaller amounts of unsaturated higher molecular weight acids. In this oil the C_{16} and C_{18} groups compose over 70 per cent of the total of fatty acids, a fact to be remembered in connection with the industrial use of this material. In the head and blubber oil of the Physeteridae large amounts of higher alcohols are found, and in addition the fatty acids differ in composition from those of other marine animal oils. In the head oil are found appreciable amounts of capric (C_{10}), lauric (C_{12}), and lauroleic acids. The unsaturated acids are exclusively mono-ethylenic ones in which the C_{14}, C_{16}, and C_{18} predominate. Unsaturated C_{20} acids are present only in small amount and C_{22} is absent altogether. In the blubber oil stearic acid (C_{18}) is not present, but a small amount of lauric occurs. In the unsaturated acids an unusually large amount of palmitoleic acid occurs together with the usual amount of oleic. The C_{20} acids in the blubber oil are slightly more unsaturated than in the head oil and there is also present a small amount of di-ethylenic C_{22} acids.

The outstanding characteristic of the blubber and jaw oils of the Delphinidae is the occurrence of large amounts of iso-valeric acid (C_5). This is one of the few acids with an uneven number of carbon atoms occurring in natural

TABLE 2
Weight Percentage Composition of Fatty Acids in Some Marine Animal Oils

	Saturated								Unsaturated					
	Un-sap. (per cent)	C_5	C_{12}	C_{14}	C_{16}	C_{18}	C_{20}	C_{22}	C_{14}	C_{16}	C_{18}	C_{20}	C_{22}	C_{24}
Teleostomi														
Clupeidae														
Pilchard (body oil)	1.0	....	....	5.1	14.4	3.2	....	....	Trace	11.7 (−2H)	17.6 (−3.3H)	17.9 (−4.1H)	13.8 (−8.5H)	15.2 (−10.9H)
Menhaden (body oil)	1.0	....	....	5.9	16.3	0.6	1.4	1.4	.....	15.5 (−2H)	29.6 (−4H)	19.0 (−10H)	11.7 (−10H)	....
Scombridae														
Tuna (liver)	....	....	....	....	17.9	8.9	....	....	.....	3.4 (−2.5H)	23.5 (−2.8H)	28.2 (−5.5H)	18.1 (−7.4H)	....
(body)	....	....	....	4.2	18.6	3.5	....	....	.....	6.2 (−2.7H)	26.0 (−3.2H)	23.5 (−5.5H)	18.0 (−6.8H)	....
Gadidae														
Cod (liver)	0.9	....	....	6.0	8.5	0.5	....	....	Trace	20.0 (−2.3H)	29.0 (−2.8H)	26.0 (−6.0H)	10.0 (−6.9H)	....
Hippoglossidae														
Halibut (liver)	6.6	....	....	3.9	15.1	0.5	....	....	.....	18.7	34.4 (−2.0H)	13.8 (−5.5H)	13.6 (−7.6H)	....
Elasmobranchi														
Alopiidae														
Thresher shark (liver)	1.8	....	....	7.5	11.0	0.5	....	....	1.5	12.0 (−2.0H)	19.0 (−3.4H)	31.0 (−6.6H)	17.5 (−10.5H)	....
Scymnorhinidae														
European shark (liver)	70-80	....	....	1.0	14.5	3.5	1.0	....	0.5	4.0 (−2H)	29.0 (−2H)	10.5 (−2H)	26.0 (−2.1H)	10 (−2.0H)

TABLE 2—(*Continued*)

WEIGHT PERCENTAGE COMPOSITION OF FATTY ACIDS IN SOME MARINE ANIMAL OILS

	Saturated								Unsaturated					
	Un-sap. (per cent)	C_5	C_{12}	C_{14}	C_{16}	C_{18}	C_{20}	C_{22}	C_{14}	C_{16}	C_{18}	C_{20}	C_{22}	C_{24}
Division Mammalia, Order Cetacea														
Balaenidae														
Whale blubber oil	....	....	....	8.0	12.0	2.0	....	....	1.5	15 (−2H)	43 (−2.3H)	8 (−7.5H)	10.5 (−9H)	....
Physeteridae														
Sperm whale (head)[a]	....	....	....	14.0	8.0	2.0	....	....	14 (−2H)	15 (−2H)	17 (−2H)	6.5 (−2H)	....	....
(blubber)	....	....	....	5.0	6.5	....	....	....	4 (−2H)	26.5 (−2H)	37 (−2H)	19 (−2.5H)	1 (−4.0H)	....
Delphinidae														
Porpoise (blubber)	....	13.6	3.5	12.1	4.7	....	....	....	4.7 (−2H)	27.2 (−2H)	16.7 (−2.8H)	10.5 (−4.8H)	7 (−4.9H)	....
(jaw)	....	25.3	4.6	28.2	4.1	....	....	....	3.2 (−2H)	20.3 (−2H)	9.3 (−2.6H)	4.9 (−4.9H)	....	....

[a] Head acids also contained 3.5 per cent capric, 16 per cent lauric, and 4 per cent lauroleic acids: the blubber acids 1–2 per cent lauric acid.

oils. It is present in larger amounts in the jaw oils than in those of the blubber. Of the unsaturated acids palmitoleic is the most important, followed by mono-ethylenic C_{18} and C_{14}. The higher molecular weight acids are only of medium unsaturation.

Marine animal oils absorb oxygen in amount roughly proportional to the iodine value. The nature of the oxidized product, however, varies with the nature of the oil. Liver and whale oils form a thick tacky product that never becomes actually solid. Some body oils, notably pilchard, sardine, and menhaden oils, on the other hand, form solid films that are nonbrittle but tacky and permeable to water. The tackiness and permeability may be overcome by preliminary heat-polymerization or by the removal of the nondrying components by means of superheated-steam distillation at high temperatures. The product of this treatment is a viscous polymer that dries very quickly to a hard, glossy, and impermeable film. Liver oils with the same iodine value as body oils do not polymerize to the same degree as the latter, and, when steam distilled, yield a small amount of viscous polymer with film-forming properties inferior to those of the polymer obtained from the body oils. All body oils do not give solid films. Salmon and herring oils remain extremely tacky and when subjected to steam distillation do not yield a very satisfactory polymer.

All marine animal oils can be hydrogenated and the product represents the greatest industrial outlet for these oils. The hydrogenation process can be made very selective in that the highly unsaturated fatty acids may be reduced to less highly unsaturated before any gross amount of saturated acids are formed. A more thorough knowledge of the hydrogenation reaction has enabled operators to produce hydrogenated fats of a wide range of saturation and melting point and to avoid the formation of so-called "iso-acids," a disadvantage in the hydrogenated fish oils of a few years ago. The degree of hydrogenation given an oil depends upon its original iodine value and the purpose for which the finished product is desired. For edible purposes and soap manufacture the product usually runs between 50 and 60 in iodine value and 40° to 45° C. in titre. A more or less completely hydrogenated product from which the total fatty acids are isolated is made, as a substitute for commercial "stearic" acid. This material is mostly used by rubber, lubricating grease, soap, and cosmetic manufacturers and the criterion by which the material is judged is usually the titre value. Titre requirements vary between 52° to 56° C., and even though the oils be completely hydrogenated, all oils do not give the same titre value for the finished acids. The titre value of a completely hydrogenated oil is definitely though not simply related to the composition of the oil. In general it may be said that the simpler the composition with respect to the number of saturated fatty acids with different carbon contents, the higher will be the titre. Thus salmon oil gives completely hydrogenated acids with a titre higher than those from herring, which in turn are higher than those from sardine oil. Unsaponifiable matter usually lowers the titre value.

Hydrogenated whale and fish oils are used to a considerable extent in the manufacture of soap. Theoretically and practically there are limits to the application of these products to soap making. The completely hydrogenated higher fatty acid soaps are insoluble in cold water and only at higher temperatures possess any detergent properties. The raw oils themselves cannot be used in soap making on account of their tendency toward rancidity. In a recent study made in these laboratories it has been established by actual washing tests that as a fish oil becomes more and more saturated by hydrogenation, the washing efficiency under any one set of conditions gradually decreases. Heat polymerization does not reduce the washing efficiency to the same degree as hydrogenation, and polymerization followed by partial hydrogenation appears to be a satisfactory way of producing a raw material for soap making that is free of a tendency toward rancidification. Whatever method is used, the object is to saturate the more highly unsaturated fatty acids without substantially raising the total amount of fully saturated fatty acids.

The sulphonation process brings out very well the dissimilar chemical properties of fish-liver and body oils. In this process, concentrated sulphuric acid is added to the oil under controlled conditions. Fish-body oils react more energetically with the acid, charring may occur, and the rather larger amount of saturated acids in these oils as compared with the liver oils leads to the formation of an undesirable sediment. Low-grade cod-liver oil is usually used as the standard raw material for sulphonated products for the leather trade and for some years the disadvantages mentioned above mitigated against the use of fish-body oils. Improved methods of sulphonation have in some degree eliminated these defects.

The chemical properties of fish oils may be used industrially in various other ways. Oil tanning of furs is dependent upon the highly unsaturated character of the fish oils used. Mention should also be made of the condensation reactions between phthalic acid, glycerol, and highly unsaturated fatty acids, that is, the so-called modified glyptal resins. Recent investigation has indicated that such resins made from the unsaturated acids of fish oils possess features that may make them of industrial value. Other condensation reactions with the highly unsaturated fatty acids of fish oils involve the addition of phenolic compounds to the double bonds. Phenol and its homologues have been added to many fish oils or their acids, but so far no commercial application has been made of the products.

With the exception of the vitamins little industrial use is made of the unsaponifiable matter of marine animal oils. The only example of any importance is the alcohol fraction of sperm whale head and blubber oils. These alcohols, present to the extent of about 40 per cent of the total oil, are used as raw materials in the production of sulphonated alcohol detergents, cosmetics, and other products. It has been suggested that the alcohols occurring in the unsaponifiable fraction of the liver oils of certain Elasmobranchii might also be used for the production of sulphonated detergents, but the quantities available are small and could hardly compete with the synthetic alcohols now produced by the high-pressure hydrogenation of fatty acids and esters. The production of synthetic vitamin D by the ultraviolet irradiation of sterols has aroused new interest in commercial sources of the latter materials, and it is possible that the unsaponifiable matter of some fish-liver oils may ultimately become of value for this purpose.

Industrial Utilization of Marine Animal Oils

Just as the availability of other facts affects the total imports of whale and fish oils into various countries, so also is the method of utilization of these oils to a high degree controlled by the nature of the fats and oils with which they are competing or which they are actually replacing. Thus in countries plentifully supplied with dairy and animal products whale and fish oils are used for nonedible purposes, while in countries that import a large proportion of their fatty foods whale oil and some fish oils are hydrogenated for edible purposes. The following paragraphs give some idea of the general use of these oils in a few of the most important countries.

Great Britain.—Of approximately 160,000 tons of whale oil consumed in this country during 1936 it has been estimated that 32.5 per cent was used in soap factories, 38.8 per cent by margarine manufacturers, 16.2 per cent for the manufacture of edible compounds such as biscuits and confectionery, and 12.5 per cent for miscellaneous industrial purposes. During the past year competent authorities assert that between 80,000 and 90,000 tons of whale oil were hydrogenated for margarine manufacture.

Fish oils such as pilchard and sardine oils are hydrogenated principally for the manufacture of edible shortenings and soaps, and smaller quantities are used, after refining, for the manufacture of certain kinds of paints and varnishes. Salmon and dogfish oils find their chief outlet in the tanning and lubrication fields, as does technical cod oil. On the basis of 1937 statistics, it is estimated that of the total fats used in the soap, margarine, and shortening industries the proportions of whale or fish oils were 16, 41, and 28 per cent, respectively.

Germany.—This country's attempt to become self-sufficient has had a very marked influence on her fat and oil market. Although definite statistics are not obtainable, it is known on reliable authority that the greatest part of the whale oil imported into Germany is hydrogenated for margarine manufacture, as also is practically all the herring oil. It is asserted that Germany's production of margarine is twice that of Great Britain, which would mean an annual production of about 180,000 tons. Herring oil not required for margarine manufacture is hydrogenated for use in soap, and the same outlet is found for most of the pilchard and sardine oils imported. In an effort to save fats for human consumption and to eliminate the loss of glycerine in cold and semiboiled soaps, stringent regulations have been placed on the German soap industry. The result has been that the industry has had to look for new sources of soap fats. The utilization of fatty acids from low-grade whale and fish oils has been successfully accomplished by a refining process involving distillation of the acids and hydrogenation. Even so, hydrogenated whale or fish-oil fatty acids could not be used indiscriminately in soap manufacture. It was held by some manufacturers that 30 per cent of the total fat charge represented the limit at which such hydrogenated fats could be used. By the use of the distilled and hydrogenated acids and a judicious adjustment of the other ingredients (obviously not divulged), soaps with from 40 to 50 per cent hardened whale or fish oils are now to be found even among the finest of toilet soaps. In the opinion of some experts these soaps are in no way inferior to those made in other countries from a wider range of raw materials.

Pilchard, sardine, and herring oils are used in common with cod oil in the German tanning industry. Moreover, the steam-distillation method of polymerization is used on these oils to produce a polymer that is apparently satisfactorily replacing "stand oil" for use in varnishes and lithographing inks. Whale oil, although not so good a drying oil as sardine or pilchard, has also received some attention for use in paints.

Japan.—Of the huge production of sardine oil some 120,000 tons are hydrogenated annually in Japan. Of this hydrogenated product some 37 per cent is used in laundry soaps, 9 per cent in toilet soaps, 2.5 per cent in spinning fats, 10 per cent in candles, 4 per cent in edible fats, 2 per cent for miscellaneous industrial uses, and about 33 per cent is split into fatty acids for export. The last-named item amounts to about 40,000 tons annually. The Japanese soap industry is developing rapidly, production in 1930 being 89,000 metric tons and in 1937 over 200,000 tons. Of this, about 8 per cent is exported. Owing to the difficulty in obtaining adequate supplies of foreign tallow, cocoanut oil, and other vegetable fats, it is the opinion of Japanese experts that in the future Japan will manufacture all her soap from hydrogenated fish oil, rice bran oil, and soya bean oil, all of which are available in Japanese territory.

The recent developments in the manufacture of sulphonated alocohols for detergents has resulted in the Japanese production of these materials from sperm whale oil and from cocoanut oil. Other known developments, for which no statistics are available, include the manufacture of drying oils and varnishes from Japanese sardine oil and the production of drying resins from the highly unsaturated fatty acids of fish oils. Miscellaneous uses of hydrogenated fish-oil fatty acids includes their addition to lubricating oils to lower the congealing point.

United States.—Practically all the whale oil produced by American companies (30 to 40 thousand tons per year) and a large proportion of the fish-oil production is used in soap manufacture, 189 million pounds of whale and fish oil being used by this industry in 1937. The rest of the American production of sardine, herring, menhaden, and salmon oils is consumed by the following industries: edible shortenings, 9.3; paint and varnish, 11.5; linoleum, 7.3; printing ink, 0.3; and miscellaneous, 17.9 per cent, of the total fish-oil production. Of the five most important drying oils, fish oil amounts to about 6 per cent of the consumption in the paint and varnish industry and about 16 per cent in the linoleum industry. The use of fish oils by all these industries has increased rapidly in the past four or five years. Besides these, the poultry- and animal-feed trade is absorbing more and more sardine, salmon, and herring oils in an effort to replace to some degree the large imports of cod and cod-liver oil. Hydrogenated fish-oil fatty acids are being used in large amounts by the rubber and allied trades and quite recently a progressive firm has made available commercial quantities of highly unsaturated fatty acids from sardine and herring oils for use in synthetic resins, varnishes, etc.

Canada.—Approximately two-thirds of Canada's production of fish oil is exported. Domestic consumption has been estimated to be divided as follows: soap, 75 per cent; paint, 10 per cent; poultry and animal feed, 5 per cent; and miscellaneous, 10 per cent. These figures refer to pilchard and herring oils only. A survey recently carried out by the writer showed that in the paint industry consumption of pilchard oil is slowly increasing as the various companies learn how to handle the oil in their different formulas. Fatty acids from hydrogenated fish oil are replacing commercial stearic acid in rubber compounding, soap, lubricating greases, and other products. The leather trades, though still consuming large amounts of cod oil, are finding that for particular purposes salmon, herring, or pilchard oils are equally well or better suited. No supplies of hydrogenated fish oils are available on the open market, and thus small soap manufacturers who would normally consume rather large quantities of this product in washing soaps and powders are unable to do so. Fish oils used in soaps are hydrogenated by the larger soap firms for their own use. In general, a steady increase in the domestic utilization of fish oils may reasonably be expected.

Netherlands.—In this country whale oil is used exclusively for the manufacture of margarine, both for domestic and export trade. Of the fish oils, sardine and cod oil appear to be used for tanning purposes, while shark liver oil, sardine, and cod liver oil are used in animal and poultry feeds. Sperm whale oil is used to a limited degree in lubrication.

Other countries.—Countries importing small amounts of fish oil use them chiefly for tanning or soap manufacture. A firm in Cuba uses large quantities of fish-oil fatty acids for the flotation of manganese ores, and in countries where sheep and cattle are raised in large numbers some fish oils are now being used in dips and sprays. Certain nondrying fish oils, such as partly hydrogenated herring oil and shark liver oils, are finding some use in insecticide sprays for the control of various pests attacking fruit trees.

Marine Source of Vitamins A and D

Although liver oils for use in industry have been mentioned in the foregoing paragraphs, any account of the economic importance of marine animal oils would be incomplete without attention to the production of liver oils for their vitamin A and D content. In spite of developments in the synthetic field, naturally occurring oil-soluble vitamins continue to be in demand. As far as vitamin A is concerned, this is not surprising. Although the constitution of this vitamin is known, it has not as yet been produced synthetically in commercial quantities, and, since its natural distribution in fish livers is very wide, such livers will in all probability remain the most important source for some time to come. The clinical use of vitamin A is increasing. In addition to the well known growth-promoting and antixerophthalmic properties, a more thorough knowledge of the function of this vitamin in the receptor mechanism of the retina and its consequent amelioration of night-blindness has had much to do with the increasing demand. Human adult requirements have been variously set at between 4000 and 5000 International Units a day.

Physical methods have demonstrated the existence of two forms of vitamin A, the new form, vitamin A_2, being found in greatest concentration in the liver oils of fresh-water fish. Up to the present no accurate data on the biological activity of this form are available.

The vitamin D situation is more complex than that of vitamin A. The probability is that at least six forms of vitamin D exist. How many of these are actually found in fish oils is not known, but it is certain that there are at least two and probably more. The vitamin D complex in cod-liver oil is more efficient when fed to chickens than the product obtained by the irradiation of ergosterol (vitamin D_2 or calciferol). The irradiation of 7-dehydrocholesterol, however, gives an active substance (vitamin D_3) that, when tested on rats and chickens, shows efficiencies equal to those obtained with the natural vitamin D complex isolated from cod-liver oil. The vitamins named above are, however, inferior to the vitamin D contained in the liver oil of the white sea-bass (*Cynoscion nobilis*), which is practically three times more efficient on chickens, rat unit for rat unit, than the vitamin D in cod-liver oil. Bills *et al.* (1937) list the "efficacy ratios" (the amount of calcification obtained for equal rat units of vitamin D, taking cod-liver oil equal to 100) of a number of fish oils, and they state: "Rat unit for rat unit, some resemble cod-liver oil, some were definitely less effective, and a few were more effective than cod-liver oil. The oils that were relatively the least potent were those from the bluefin tuna of California, oriental tuna, striped tuna, bonito, albacore, and totuava. The relatively most effective oil was that from the white sea-bass of California." It is interesting to note that sardine-body oil was equal in efficiency ratio to that of cod-liver oil, while the vitamin D in shark- and dogfish-liver oils, although present in only small amounts in these oils, is relatively more effective than that in cod-liver oil. It must be emphasized, however, that the efficiency ratios of fish-liver oils do not remain constant, but, like the total vitamin D potency, may vary appreciably, even in different samples from the same species.

It is impossible to list the factors that influence the vitamin potency of fish and fish-liver oils in any fixed order of importance, as factors that are of primary importance in one species of fish may be of insignificant importance in another species. Added to this are the enormous individual variations met with in any one species and the lack of adequate statistical data for many species now used as commercial sources of vitamins. However, an attempt has been made in figure 2 to show the general relative importance of some of these factors. Species has been given the primary role, although strictly speaking this should be extended to families or even orders. The variation according to families is discussed in greater detail in a later paragraph. In almost all species the vitamin content of the liver increases with the age of the fish. This is definitely true of the vitamin A content of halibut livers (Pugsley, 1939), but curiously enough does not seem to hold for the vitamin D content. It has recently been reported, also, that although the age group of Icelandic cod is increasing from year to year, the vitamin A potency is apparently receding. On the other hand, the vitamin A content of Newfoundland cod-liver oil seems to be proportional to the age of the fish. According to work done in these laboratories by Dr. L. I. Pugsley, vitamin A reserves in grayfish and gray-cod livers increase with increasing size of the fish. In the latter, the older fish also contain more vitamin D.

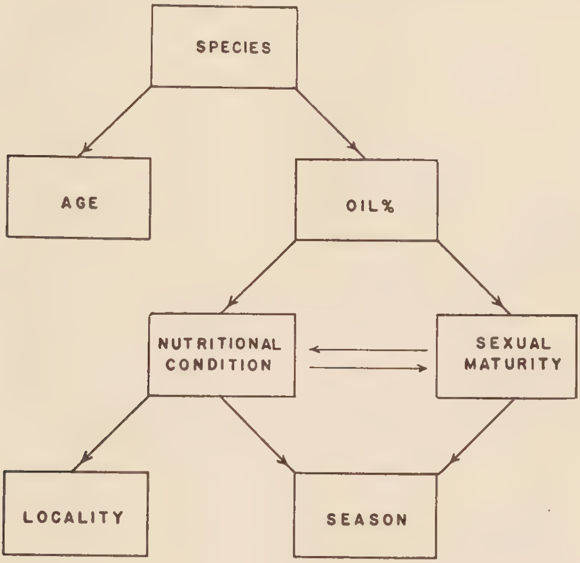

Fig. 2.

It has been well established that the vitamin A potency of fish livers varies inversely with the liver-oil content. This factor is superimposed on the total vitamin content of the liver as affected by the species and age and appears to be due to the greater nutritional need by the animal for fat than for vitamin A. The liver-oil content or the total fat content is a function of the sexual and nutritional condition of the fish. Fish that do not feed during the spawning period show wide fluctuations in total oil content. During the subsequent feeding period, the oil content increases, the rate and amount of the increase depending upon the feeding habits of the fish (species) and the abundance of food. The latter is in turn a function of locality and season. It will thus be apprehended that the factors that control the vitamin potency of fish and fish-liver oils are very much interrelated. For example, it has been observed

TABLE 3

Distribution of Vitamins A and D in Some Liver Oils

	Common names	Distribution	Vitamin A	Vitamin D
Order Percomorphi				
Family: Scombridae	Blue-fin tuna, yellow-fin tuna, albacore, bonito, Pacific mackerel, striped tuna, or skipjack	World-wide distribution and tendency to southern warm waters, i.e., Columbia River to southern California	20,000–500,000	5,000–60,000
Carangidae	California yellowtail, horse mackerel	Coast of California	50,000	17,000
Xiphiidae	Swordfish	World-wide, warm seas, Norway to Cape of Good Hope	10,000–400,000	2,000–12,000
Sphyraenidae	California barracuda	California coast	40,000	2,000
Sciaenidae	Totuava, croaker	Warm seas, Pacific and Atlantic	50,000–100,000	
Gempylidae	Australian barracouta	Southern Pacific	30,000– 70,000	Up to 300
Serranidae	Black sea-bass or jewfish, rock-bass, cabrilla, grouper, ishinagi, etc.	Warm seas, Atlantic and Pacific	15,000–500,000	1,000– 4,000
Order Anacanthini				
Family: Gadidae	Pollock, haddock, cod	Both shores of Atlantic	500– 5,000	50– 250
Merluciidae	Hake	Both shores of Atlantic, particularly of America	500– 3,000	50– 250
Order Heterosomata				
Family: Hippoglossidae	Halibut	North Atlantic and Pacific	8,000–200,000	1,000– 5,000
Pleuronectidae	Flounders	Cold waters	14,000– 42,000	1,000– 2,000
Soleidae	Soles	Temperate waters		1
Bothinae	Turbots	Atlantic European coast, Italy to Norway	50,000 and up	
Order Isospondyli				
Family: Clupeidae	Pilchard, herring, Japanese sardine, menhaden, sprat, shad	General distribution, more particularly in temperate waters	50– 100	20– 80
Salmonidae	Salmon	Pacific and Atlantic coasts in temperate waters	5,000– 40,000	100– 600

TABLE 3—(*Continued*)

DISTRIBUTION OF VITAMINS A AND D IN SOME LIVER OILS

	Common names	Distribution	Vitamin A	Vitamin D
Order Cataphracti				
Family: Anoplopomidae	Sablefish or black cod	Pacific coast of North America, temperate waters	15,000– 60,000	600– 1,000
Hexagrammidae	Ling cod, cultus cod	Pacific coast, Northern California to Alaska	50,000–500,000	1,000– 6,000
Scorpaenidae	Boccacio, chili-pepper, red snapper, and rockfishes	Pacific coast, temperate waters	50,000–500,000	300– 5,000
Order Jugulares				
Family: Anarhichadidae	Wolf fish	North Atlantic and Pacific	1,000	20
Order Tectospondyli				
Family: Squalidae	Dogfishes	World-wide distribution	500– 20,000	5– 25
Order Batoidei				
Family: Rajidae	Rays and skates	Coastal waters, Atlantic and Pacific	100– 1,000	5– 25
Order Holocephali				
Family: Chimaeridae	Ratfishes	General distribution in temperate waters	100– 500	5– 25
Order Eusalchi				
Family: Cetorhindae	Basking shark	All northern coasts, particularly North Sea and off California	0– 500	
Galeidae	Blue shark, soup-fin shark	Almost all coasts and warm waters	1,000–150,000	5– 25

in many publications that fish with high vitamin D reserves are usually caught in southern, warm waters; those from more northerly and colder waters, though often possessing an ample amount of vitamin A, never show high vitamin D potencies. Whether this is a species or temperature effect cannot be definitely stated at present, as fish with such high vitamin D reserves are indigenous to the more southern waters and sufficient data are not available from the relatively few individuals that are sometimes taken in more northerly waters.

In table 3 some of the fishes the livers of which are important sources of vitamin A and D are listed under their orders and families. Several interesting relationships between vitamin potencies and biological classification are evident. The Percomorphi are outstanding in their high vitamin D content, the only other order approaching them being the Cataphractic, and to a more limited degree the Heterosomata. These three orders also embrace the fish the livers of which are the most potent in vitamin A, although, as mentioned before, the vitamin A content does not necessarily parallel that of vitamin D. This is shown very well by the Isospondyli, particularly the Salmonidae, in which vitamin A potencies may range as high as 40,000 units but the vitamin D never rises above 600 units per gram. The order Anacanthini, in which occur fish supplying a large part of the commercial vitamins, shows but medium potencies in both vitamin A and D, with larger variation in the former. Finally, the two orders from the Elasmobranchii, the Tectospondyli and Eusalachi, show wide variations in vitamin A and almost no vitamin D. The lack of vitamin D appears to be characteristic of fish with a cartilagenous skeleton such as is possessed by the members of these groups and is in some way related to their primitive development and limited calcium requirements.

TABLE 4

THE VITAMIN POTENCIES OF SOME FISH VISCERAL OILS

Kind of fish	Percentage of Oil	Vitamin A	Vitamin D
Halibut	1– 5	24,000–480,000	100–500
Ling cod	8–16	30,000–170,000	100–200
Black cod	4–10	12,000– 96,000	100–200
Red cod	4–10	12,000– 96,000	200–500
Gray cod	1– 5	9,600– 48,000	....
Salmon			
Steelhead	20–40	1,200– 2,400	....
Sockeye	4– 8	12,000– 24,000	....
Chum	2– 4	600– 1,200	....
Pink	2– 4	6,000– 12,000	....
Spring	2– 4	1,200– 6,000	100–200
Grayfish	2– 4	2,000– 4,000	....

In fish the livers of which are not the main fat storage depot it is usually found that both vitamin A and vitamin D are associated with the fat of other tissues. This is particularly true of the Isospondyli and Percomorphi, the body fat of their members containing appreciable amounts of these vitamins. Another interesting feature of the vitamin reserves in fish is shown in the vitamin A and D contents of visceral oils. The writer is indebted to Dr. L. I. Pugsley of these laboratories for the data given in table 4, which show very much larger concentrations of vitamin A than of vitamin D. The vitamin A seems to be present in the mucosa of the intestine, while there appears to be an indication that vitamin D is found in the spleen. The mesentery, although sometimes loaded with fat, is usually lacking in vitamins. Obviously, the vitamin potency of the visceral oils will vary inversely with the total oil content, but the mechanism of the selective accumulation of vitamin A is at present unknown.

The methods used for the production of liver oils, depend in large part upon the type of liver. Livers of the Anacanthini and also those of the Elasmobranchii are usually so oily and the liver proteins of such a nature that the oil is easily removed by steaming methods. Modern methods for the manufacture of cod-liver oil embrace the use of high-pressure steam and thorough boiling of the livers to insure the complete inactivation of enzymes and destruction of bacteria. The livers of the fish in the remaining orders, as exemplified by those of the Percomorphi and Heterosomata, are much more difficult to deal with. The oil content rarely exceeds 15–20 per cent and the liver proteins, when heat coagulated, are very absorbent and retain practically all the oil liberated by the heat treatment. For this type of liver various digestion processes have been devised, the object being to dissolve wholly or partly the proteins having the minimum effect on the oil. This is accomplished either by enzyme digestion followed by peptization with mild alkalies, or by total digestion with alkalies or acids. The dissolved protein-and-oil mixture is then put through a centrifuge and the oil removed. Complicating factors are the surface effects of soaps and peptized proteins that selectively adsorb the vitamins from the mixture and necessitate careful treatment of the aqueous phase in order to avoid serious losses of vitamins. This latter is particularly true of intestinal material in which the oil content is low and the proportion of free fatty acids in the raw material high. For these materials digestion methods do not appear to be suitable and recent investigation indicates that a modified solvent extraction process is more efficient.

The trend in vitamin preparations today is toward concentrates in which form prophylactic and curative doses can be administered in capsules. For this reason the liver oils of high potency from Percomorphi and Heterosomata are much in demand, the livers themselves bringing from 40 to 90 cents a pound. The recent large-scale production of certain shark-liver oils, notably soup-fin shark oil, with vitamin A potencies of 100,000 units and up, has had a depressing effect on vitamin A prices. The vitamin A content alone, however, does not set the price of an oil. Since the larger proportion of these oils is used for making concentrates, the ratio of vitamin A or D to the total unsaponifiable matter present represents the practical limits of concentration, and thus oils with low unsaponifiable matter and high potency are in demand. The liver oils from the fish in the Anacanthini group are still finding ready markets, but even here large quantities are now being used for concentrates. The total body oils of the Isospondyli are being used in rather large volume for poultry and feeding oils, usually with the vitamin potency standardized by admixture with more potent liver oils.

Future Investigations

One hesitates to venture an opinion of the direction any industry will take in these days of world unrest, but one or two lines of fundamental importance seem to the writer to be worth investigating. In regard to industrial marine animal oils, the characteristic feature, as we have seen, is the occurrence of highly unsaturated fatty acids. In no other industrial materials do such highly unsaturated acids occur. Chemists can saturate, with some degree of control, the centers of unsaturation in organic compounds, but we have yet to learn how to create, with equal precision and facility, these same centers of unsaturation. The unsaturated acids of marine animal oils represent highly reactive materials which should be utilized with reference to their multiple double bonds, yet the greatest commercial utilization of these substances is in the hydrogenated or reduced form. The most economic method of utilization would appear to be associated with those reactions which require a system of multiple double bonds, as in certain condensation and polymerization reactions, and no doubt in the future these acids will be so used.

Another investigation, of less fundamental importance but of some present economic significance, relates to the isolation of vitamin D from such oils as sardine and herring which are produced in large quantities but in which the vitamin D concentration is of a relatively low order. If the vitamin D could be isolated from such oils without impairing them for industrial use, a very important source of this vitamin would become available. Already this is possible by means of short-path high-vacuum distillation, but whether or not this method represents the most economical approach to the problem remains to be seen. In other laboratories the problem is being variously attacked, and it is to be hoped that a solution will be found in the near future. When it is solved, natural vitamin D will be as easily and as cheaply obtainable as vitamin A is at present.

ACKNOWLEDGMENTS

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SOME CHEMICAL AND BIOLOGICAL ASPECTS OF THE MANUFACTURE AND DISTRIBUTION OF FISH MEAL

By R. W. Harrison

Fish meal is one of the most important fishery products in world commerce. The total annual production in countries for which statistics are available exceeds 1,000,000 tons, valued at approximately $30,000,000 (table 1). In order to produce this quantity of meal, reduction industries utilize at least 12,000,000,000 pounds of whole fish and fish trimmings each year and the demand for raw materials thus created is providing incentive for some of the largest commercial fisheries in the world. This is particularly true in the Pacific area, where 80 to 90 per cent of the world supply of fish meal is prepared.

TABLE 1

Latest Statistics of World Production of Fish Meal, Scrap, Etc.

Country	Year	Quantity (tons)	Value (dollars)	Average value per ton
United States	1937	219,565	7,554,326	34.40
Canada	1937	51,127	1,262,786	24.70
Germany	1937	8,617	....	.....
Iceland (exports)	1937	33,479	230,014	6.87
India (exports)	1932	6,323	171,812	27.17
Japan	1936	497,268	10,868,250	21.85
Formosa, Korea, Kerafuto	1935	280,000[a]	6,119,899	21.85[b]
Mexico	1930	148	....	.....
Netherlands	1937	5,512	....	.....
Newfoundland	1933	554	11,265	20.33
New Zealand	1938	18	118	6.56
Norway (exports)	1937	45,713	2,202,390	48.18
Sweden	1931	2,513	112,014	48.55
Tunisia	1936	55	550	10.00
Union of South Africa	1931	14,621	366,930	25.10
Total	......	1,165,513	28,900,354	

Source:
Data supplied by United States Tariff Commission.

[a] Estimated by writer on basis of value and average price per ton of fish meal in Japan.

[b] Values assumed by writer to be same as for Japan.

Generally speaking, it is not economically feasible to reduce fish for the sole purpose of making meal unless the raw material is available at very low cost. Therefore, except in the utilization of certain types of fish waste, fish meal is prepared from fatty fish in conjunction with the manufacture of fish oil. The process almost always consists of cooking the raw material, pressing the cooked mass, separating the oil from the expressed liquids, and dehydrating the pressed residue. Equipment and methods vary from wood-fired cooking kettles, crude hand-manipulated presses, skimming vats, and sun drying, to continuous steam cookers, presses, centrifugal oil separators, rotary steam and hot air driers, grinders, and conveyors, power driven and synchronized so as to permit treatment from raw material to finished product without interruption or having to be handled by man. North American and European countries have been most aggressive in developing and adopting mechanized equipment, but increasing amounts of meal are now being prepared in modern plants in all countries.

The advancement made in reduction methods has been restricted for the most part to improving the efficiency and increasing the capacity of basic equipment and to the introduction of labor-saving methods. The fundamental principles of the reduction process, however, have remained essentially unchanged; therefore, there are a number of aspects of fish-meal manufacture which are of common interest, regardless of the degree of refinement of the equipment.

Whole fish and fish trimmings of the type utilized in the manufacture of fish meal normally have an oil-free solids content of about 19 to 23 per cent. The other 77 to 81 per cent may be accounted for as moisture and oil. As a general rule, when fish vary in fatness, there is a corresponding and inverse variation in moisture content; thus, regardless of the degree of fatness, the proportion of protein and bone material in the whole remains relatively constant. The potential yield of meal after relatively complete oil removal should be about 400 to 475 pounds per ton of raw material. In actual practice the average yield is about 325 to 400 pounds.

The differential between actual and potential yield is due to the fact that a considerable amount of nitrogenous material passes into solution during the cooking process and subsequently is discarded in the stick water along with varying amounts of fine suspended solids material. Analyses of stick water show that the proportion of original raw material discarded as suspended solids and soluble material normally ranges from 1 to 5 per cent and 15 to 20 per cent, respectively. Cooking and pressing also removes certain vitamin factors, presumably belonging to the vitamin B complex. One of these factors, riboflavin, has an important rôle in nutrition and its loss during reduction detracts from the potential versatility of the meal when used as a protein concentrate in animal rations.

In recent years the meat-packing industry has in large part discontinued the tankage process of handling slaughterhouse waste, a method similar to that used in fish reduction, and has adopted dry rendering. In the dry rendering procedure the raw material is dehydrated and the liberated fat is then expressed from the dry residue. Loss of any type of water-soluble extractive is eliminated and the raw material entering the process is recovered completely as finished products. Unfortunately the method does not lend itself as readily to fish reduction as it does to the handling of meat products.

Manufacture of fish meal and fish oil is strictly a seasonal operation, seldom lasting more than a few months. Under these circumstances it is desirable that the equipment used permit high capacity without an excessive investment, since the investment lies idle seven to nine months in the year. The modern fish-meal plant meets this requirement much better than a dry rendering plant because moisture can be removed more rapidly and with less cost by cooking to coagulate protein and pressing out the liberated moisture than by depending entirely upon evaporation. Data obtained in the laboratories of the Bureau of Fisheries have demonstrated that over a long season of operation the increased yield per unit of raw material permitted by dry rendering will equalize the greater manufacturing cost, but it is problematical that this could be expected in a season of normal length in which the same total quantity of raw material would be handled.

The dry rendering process is subject to another disadvantage in that heating fish flesh and fish oil in contact with metal during the course of dehydration normally causes serious discoloration of the oil. Experimental work in our laboratories has indicated the possibility of minimizing this difficulty, but in view of the higher manufacturing costs mentioned above and the existing investment in present equipment, the dry rendering process is seriously handicapped as a means of increasing fish-meal recovery.

Inasmuch as the dry rendering method has not appeared to be a practical solution of the problem, a few members of the American industry are giving attention to methods of recovering stick-water losses. One procedure is to concentrate the stick water to a thick syrup in multiple-effect evaporators, mix the concentrate with the press cake, and then dry the mixture in the usual manner, so that the resultant meal contains the original nitrogenous components and vitamins subject to any alteration occurring during the recovery process. Concentrated stick waters are being added to cooked fish material and possibly to other feed material in the preparation of canned foods for pets and fur-bearing animals. Concentrated stick waters, also, are being spray-dried in commercial experiments and the properties of the dry product are being investigated. Because of the relatively high vitamin G potency of stick waters, the concentrate and dried flour are potential vitamin concentrates for inclusion with fish meal and other feeds in preparing balanced rations for poultry and animal feeding. It is also possible that the concentrated or dehydrated material may be found to have utility for inclusion in technical products. The progress which has been made is admirable, but because additional and expensive equipment is required and the operator is in effect assuming a new operation which must be carried on simultaneously with the basic reduction process, adoption of such recovery methods is proceeding slowly. In the meantime several billions of pounds of nitrogenous material will continue to be discarded annually throughout the world unless corrective methods are applied.

It is known that protein materials are subject to various physicochemical phenomena. For example, the solubility of protein materials varies with hydrogen ion concentration and for each protein there is a pH range in which it is least soluble. Proteins may be precipitated from solutions by electrolytes, particularly polyvalent salts or salts of heavy metals, by so-called alkaloidal reagents, and by various other chemical coagulants. It is possible, therefore, to decrease materially the tendency of fish proteins to go into solution during cooking by pretreatment with coagulating or precipitating agents under controlled conditions. Some commercial progress has been made, and experimental work is being done. In the writer's opinion this field offers an attractive approach to the problem of stick-water losses, because its purpose is preventative and the principles involved could be applied in conjunction with existing equipment without appreciably altering operating procedure. The primary considerations, besides effectiveness, would be the relative cost of chemicals and whether or not they would leave toxic residues. While it cannot be expected that such treatment will completely eliminate stick-water losses, the greater possibility for general adoption would more than compensate for any lack in efficiency. An example of the control which can be exercised over the solubility of nitrogenous material of fish during cooking is shown in figure 1.

In the preparation of fish meal from fatty fish, it is not possible, by the methods being used, to obtain a complete separation of the oil from the flesh. Accordingly, practically all fish meals contain some oil, the majority having an oil content varying between 5 and 12 per cent. The presence of an oil in fish meal offers a number of serious obstacles and contributes to some of the most aggravating situations associated with fish reduction.

Fish oils are, as a general rule, rather highly unsaturated compounds which combine readily with the oxygen of the air. Hence, fish meals containing oils are subject to oxidation during manufacture, immediately thereafter, and during subsequent storage. The rate of oxidation is so great immediately following grinding that the meal heats spontaneously and unless precautionary measures are taken the meal may catch fire.

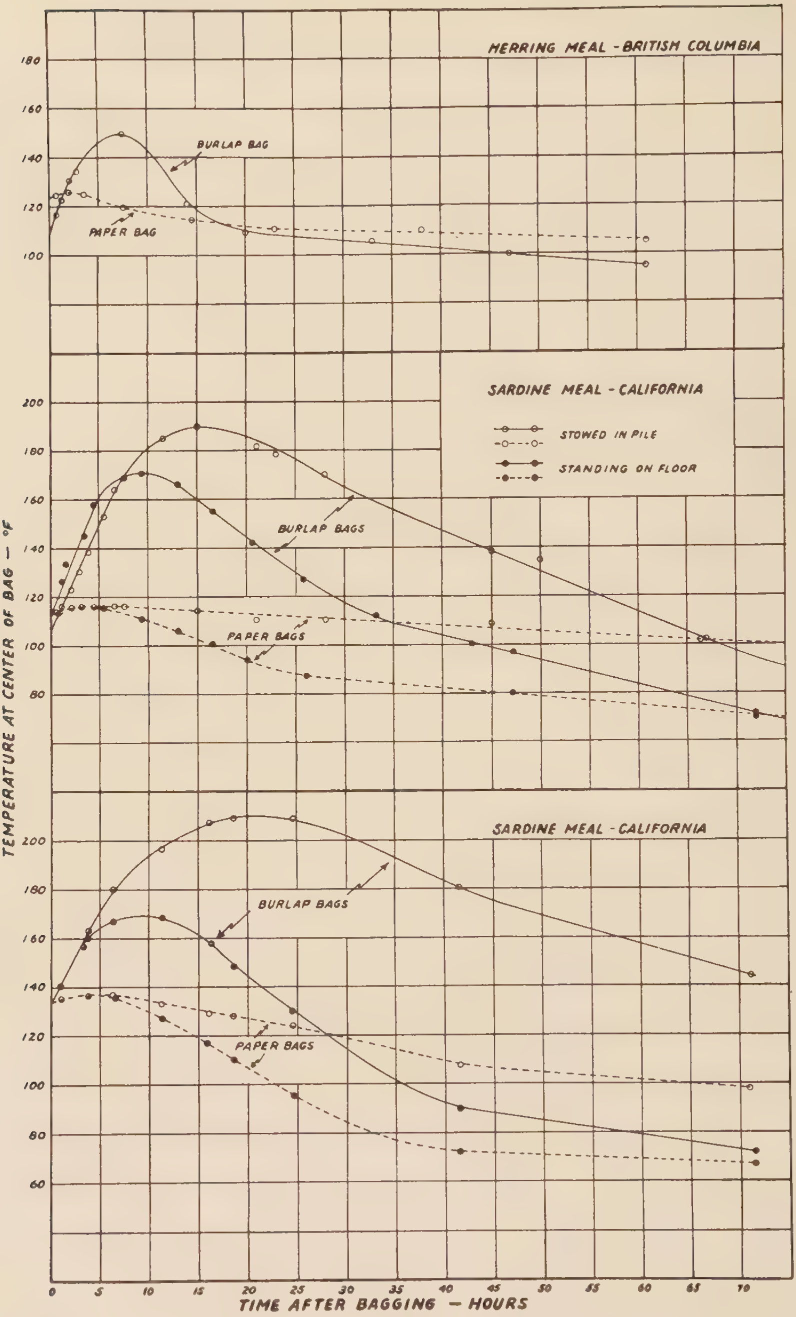

Fig. 1. Temperature changes in fish meal just after grinding when stored in burlap and multiwall (4 kraft, 1 asphalt) paper bags.

In normal practice the dried unground material emerging from the drier is either spread in a thin layer on the floor for 24 to 48 hours before being ground to meal or it is ground and bagged immediately and the bags are set on end on the floor in minimum contact with one another and allowed to stand 24 to 72 hours before being tightly stowed in piles or loaded for shipment. As a general rule, meal which has been cured on the floor also is stowed loosely for 24 to 48 hours after grinding. By using these precautions the heat of oxidation is dissipated quite rapidly and the danger of excessive heating is minimized, although the temperature of the meal in the center of the bag may increase some 50° to 100° F. in the course of the first six to twelve hours. Meals lower in oil or prepared from fish yielding oils of lower iodine number do not tend to heat so severely and can be handled with somewhat greater dispatch.

In giving critical consideration to the precautionary measures taken in the handling of fish meal, it is seen that they are palliative rather than corrective. The operator does not prevent oxidation; instead, he causes it to proceed under his control. The procedure partly solves the practical problem of heating and resultant fire hazard, but it still subjects the meal to pronounced chemical change. The consumer receives a highly oxidized product at best and it is doubtful if anyone knows the potential food value of a fresh, unaltered fish meal. Therefore, since existing practice causes inconvenience, increased handling costs, and greater storage requirements while still permitting changes in the product detracting from its potential utility, a more satisfactory solution to this problem should be sought.

From a purely theoretical standpoint the ideal procedure would be to remove the troublesome oil by solvent extraction. The method, however, is subject to about the same type of handicap as dry rendering. A more likely field of approach, as far as possibility of acceptance is concerned, would appear to be in methods designed to prevent oxidation. Two such methods may be suggested, namely, pelleting and the use of air-proof containers, either of which might be facilitated by incorporating harmless antioxidant materials in the meal.

The idea of compressing freshly prepared fish meal into pellets was first conceived several years ago in connection with the problem of handling meal aboard floating factory ships. A commercial installation was made and the initial results were reported as satisfactory, but the vessel discontinued operations shortly thereafter and no further commercial work has been reported. In a preliminary test made on an experimental meal prepared in our laboratories, a pelleted sample, after twelve months' storage, showed less oxidation of oil than similar meal which had not been pelleted. These meager observations, while not warranting further discussion, suggest the desirability of further study on this method of preventing oxidation in fish meal during storage.

Food-products industries have made some progress in retarding oxidation in fatty foods by the adoption of various types of air-proof containers. A similar procedure would appear to have possible merit in the handling of fish meal, providing it did not contribute to some detrimental effect of another type. In the past year, experiments of this nature have been carried on which demonstrate quite conclusively that the danger of heating can be practically if not entirely eliminated. Sufficient time, however, has not elapsed to permit observations on the stored products to determine how much oxidation takes place during extended storage or if any undesirable condition arises.

Fish-meal plants do not always turn out a meal of uniform moisture content; so it is necessary to know the maximum moisture content permissible before a moisture-proof and air-proof container would contribute to other types of decomposition caused by the dampness of the meal. It must be determined definitely whether or not an air-proof container will contribute to mold growth. Also, since fish meal has a characteristic odor, it is necessary to determine if there would be an accumulation of volatile compounds leading to an altered or undesirable odor. The need for corrective measures in meeting the problems resulting from the oxidation of fish meal is sufficiently great to warrant the serious attention of the fisheries investigator. The curves in figure 2

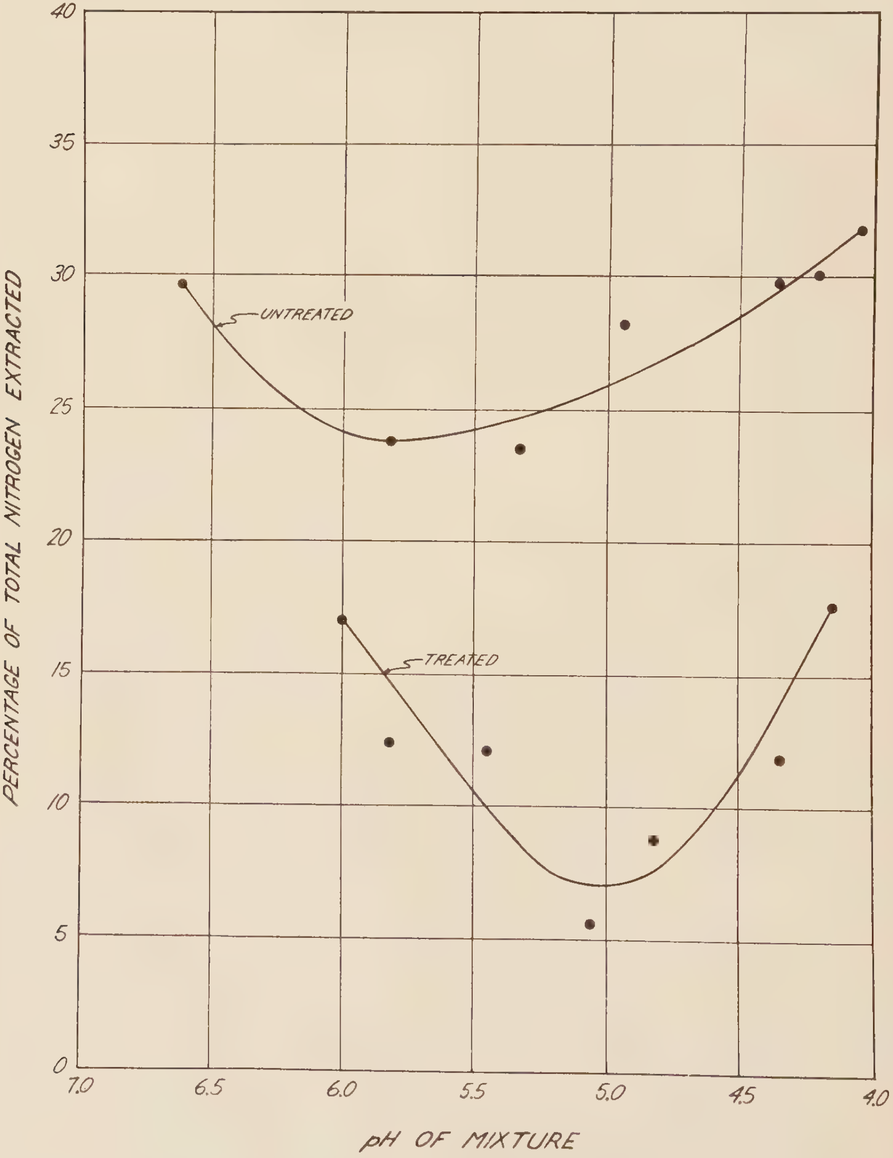

Fig. 2. Changes in the solubility of nitrogenous material in salmon waste during cooking as affected by pretreatment with a chemical coagulant (formaldehyde) and/or by prior adjustment of the pH of the fish waste–water mixture.

illustrate the effectiveness of the multiwall asphalt-treated paper bags in eliminating spontaneous heating in various types of fish meal.

When the oil in fish meal becomes oxidized, it becomes less soluble in normal fat solvents; thus during the period of heating previously discussed, the oil content of the meal as indicated by "ether extract" value will appear to decrease. A similar situation pertains during subsequent storage, and within a period of several months the apparent oil content may be as much as 50 per cent under its regular value. This condition, together with the fact that uniform methods for determining fat are not followed in testing laboratories, has given rise to a confusing situation in sale and distribution because many buyers specify a definite limitation in the amount of oil which can be present in the meal purchased.

When other than fresh raw materials are used in the manufacture of fish meal, various end-products of both protein and fat decomposition may be expected in the finished product. When crude methods of manufacture necessitate delays between the various steps in the process, further deterioration will normally take place. If meal is dried at excessive temperatures or moisture is not removed with sufficient rapidity, as may occur in attempted natural air drying in inclement weather, nutritional properties may be impaired and other breakdown of the material may occur. Similarly, improper handling methods after manufacture may lead to detrimental chemical and biological changes, other than those previously mentioned with regard to oxidation. With the possible exception of the natural tendency toward oxidation, the other forms of change which impair quality can be controlled if a reasonable amount of care is taken. Unfortunately this is not always the case.

If fish meal is to attain full recognition for the inherent chemical and biological qualifications which give it advantage over other protein concentrates, means should be provided the buyer for differentiating between desirable and undesirable materials prior to sale. When this is attained, there will be a greater premium for the product having the most desirable properties and the manufacturer will have greater incentive for preparing a higher-quality product. Development of more reliable methods for evaluating the properties and composition of fish meal will be a definite aid in this direction and offers a field of study which is deserving of greater attention.

The several chemical and biological aspects of fish-meal manufacture and distribution which have been discussed and the problems arising therefrom are common to the countries of the Pacific and will be closely associated with the future progress of fish-reduction industries. The elimination of waste during manufacture is not only economically sound, but is, in fact, a type of conservation, since less drain would be required on a fishery to produce the same quality of finished product. Prevention of oxidation in fish meal during manufacture and storage has the possibility of reducing production costs and giving the customer a more desirable product having greater utility in animal feeding. Improved methods for evaluating the composition and properties of fish meal offer promise of promoting more intelligent purchasing and distribution, and a general improvement in the quality of fish meal in the Pacific area.

THE HOMING INSTINCT IN TROUT AND SALMON

By Leo Shapovalov

Introduction

For a number of years the majority of biologists working with the anadromous forms of salmon have spoken of spawning adults returning to the "natal" or "parent" stream, that is, the stream which they had left as young fish, after sojourns of longer or shorter duration at sea, and have referred to this phenomenon as "homing" or the exercise of a "homing instinct." Their views had received but little serious opposition of late until the appearance of an article in Science for March 26, 1937, by A. G. Huntsman, entitled " 'Migration' and 'Homing' of Salmon" (Huntsman, 1937*a*), which started a worldwide controversy. Dr. Huntsman had also expressed his views in Bulletin 51 of the Biological Board of Canada (Huntsman, 1936). These articles referred primarily to the Atlantic salmon (*Salmo salar*), which is generally considered to be allied more closely to the steelhead trout (*Salmo gairdnerii*) of the Pacific coast of North America than to the Pacific salmons (genus *Oncorhynchus*). The main thesis of Dr. Huntsman's paper in Science is as follows:

> "On inquiry and examination of the literature I have failed to find a single clear case of a salmon returning to its natal river from a distant place in the sea, that is, away from the neighborhood of the river mouth. Admittedly this is a difficult thing to prove, since we must be sure of three things for the individual fish: (1) Which is its natal river? (2) where it has been in the sea, and (3) that it is again in its river. Perhaps someone may be able to produce such evidence. Without it, however, it seems pointless to speak of a 'homing instinct.' "

Dr. Huntsman's article was partly answered by Willis H. Rich in an article in Science for May 14, 1937, entitled " 'Homing' of Pacific Salmon" (Rich, 1937*a*). The controversy then raged back and forth in Science, with further articles by Rich (1937*b*) and Huntsman (1937*b*) and an article by Frederick A. Davidson (1937). Dr. Huntsman continued the presentation of his case in the Salmon and Trout Magazine (Huntsman, 1938*a*) and Nature (1938*b*) and his challenge was taken up by both European and American scientists in that journal (Calderwood, 1937; Dahl, 1939) and the Pacific Fisherman (1937*a*, 1937*b*, 1937*c*). An article by Taft and Shapovalov (1938) entitled "Homing Instinct and Straying Among Steelhead Trout (*Salmo gairdnerii*) and Silver Salmon (*Oncorhynchus kisutch*)" in California Fish and Game for April, 1938, was not a result of this controversy, but fitted into it. The writer has also had some correspondence with Dr. Huntsman and others on this subject. Persons interested in the details of the controversy and of the evidence for and against the homing theory should refer to these papers, which in turn contain references to much of the important work done in this field. The article by Dahl (1939) is particularly illuminating and answers the points presented by Dr. Huntsman in his paper in the Salmon and Trout Magazine (Huntsman, 1938*a*).

Before a discussion of the subject is undertaken, it might be well to point out that Henry B. Ward and Louis Roule are the chief exponents of the view that in selecting their spawning grounds salmon respond tropistically to specific stimuli in their environment, a view essentially in conflict with the parent stream theory. Roule believes that the responses are to a higher oxygen content, Ward that they are to colder water. In the natural fresh-water environment of trout and salmon, higher oxygen content and colder water are usually associated and so mean one and the same thing. Dr. Huntsman's views seem to occupy an intermediate position between the views of Ward and Roule and those of the proponents of the home stream theory.

It might also be well to point out the importance and significance of this subject. Legislation, stocking methods, and management methods in general for the vast salmon and anadromous trout fisheries, especially of the Pacific coast of North America, are intimately tied up with the home stream theory. A. L. Pritchard (1932) pointed out that "probably the most important factor in the general consideration of the conservation of Pacific salmon is the regulation of the commercial catch in such a way that the escapement of mature individuals to the spawning beds will provide a seeding adequate to perpetuate the run." But if homing does not exist, the perpetuation of the run cannot be expected to depend upon the seeding in any given stream.

DISCUSSION

Unfortunately, the discussion of this whole subject in the course of the present controversy has been greatly clouded and complicated by the interjection of several distinct issues or problems, without their consideration in logical sequence. It is now rather difficult for someone not thoroughly acquainted with all the aspects of the controversy to "see the forest because of the trees." Consequently, the purpose of this paper is not so much to review or summarize all of that which has been said for and against the homing theory, which can be done by referring to the papers mentioned previously, but rather to make the issues at stake somewhat clearer by breaking down the subject into its component parts. This the writer will attempt to do by asking and then answering, as far as possible, the following questions:

1) *By whatever name we call it*, does the phenomenon that we call "homing" exist to any degree?

2) If it does exist, how much deviation is there, that is, to what degree does "straying" take place, both to and from the stream in question?

3) If it does exist, how far may the fish travel without getting "lost"?

4) If it does exist, what is the mechanism by which it operates?

5) If it does exist, what name should we properly assign to the phenomenon?

It is readily seen that the latter four questions are dependent on the first: "*By whatever name we call it,* does the phenomenon that we call 'homing' exist to any degree?" To the writer the answer is clearly, "Yes." The facts are, simply, that if we mark either artificially reared or naturally propagated trout or salmon of sea-run stock and liberate them in a stream with access to the sea, *as a general rule* a number of them will pass out of that stream into the sea in the course of a definite seaward migration and will return several months to a few years from that time as spawning adults. Numerous papers by European and American workers, mentioned previously, have shown these basic statements to be true, and reference should be made to these papers for details of the experiments. So far as stocking, management, and fishery regulation are concerned, the phenomenon of return is the thing of prime importance, providing the number of fish returning is sufficiently large. Just how large this number may be is shown in the answer to the second question, which is: "If it does exist, how much deviation is there, that is, to what degree does 'straying' take place, both to and from the stream in question?" Experiments in two small streams in California, Scott and Waddell creeks, which flow directly into the Pacific Ocean and are *only four miles apart* at their mouths, show (Taft and Shapovalov, 1938) that, over a period of four years, of steelhead trout marked as seaward migrants at Waddell Creek 233 (97.9 per cent) returned there as spawning adults after one or more seasons at sea and only 5 (2.1 per cent) strayed to Scott Creek; of the trout marked at Scott Creek, 559 (98.8 per cent) returned there and only 7 (1.2 per cent) strayed to Waddell Creek. Results with individually numbered tagged adult steelhead trout that had spawned once were substantially the same. Several tagged adult fish returned to Scott Creek three years in succession. Among silver salmon in the same streams, 133 (79.2 per cent) returned to Waddell Creek and 35 (20.8 per cent) strayed to Scott Creek. It is extremely interesting and may prove of some significance that the percentage of straying for the two species is different, yet quite consistent for each species during different years.

Experiments conducted by Taft and Shapovalov (1938) in the Klamath River, California, showed that even *within a large river system* the amount of straying among sea-run steelhead trout was no greater than between the small coastal streams Waddell and Scott creeks. The Klamath River experiments consisted of liberating marked fish in certain tributaries 160 to 196 miles above the mouth of the main river. Many large and small tributaries supporting steelhead trout runs flow into the Klamath River between these points and its mouth.

That there should be some straying is to be expected; exceptions are characteristic of most biological phenomena.

The third question is: "If it does exist, how far may the fish travel without getting 'lost'?" This question may be divided into two parts: (1) How far may the young fish travel from the point at which they started their seaward migration and still return to their home stream? (2) How far from the mouth of their home stream may the fish travel at sea and still return to their home stream? As for Atlantic salmon in Europe and the Pacific salmons, experiments of other workers indicate that definite migrations at sea hundreds of miles in extent do take place. The conclusions drawn from these experiments seem valid to the present writer, but since they have been attacked by Dr. Huntsman as being based on evidence that is too circumstantial, and since the present writer is better acquainted with the migrations of steelhead trout, let us examine some other data. We have but little information on the movements of this species at sea; in California there is no commercial fishery for trout and very few are caught at sea by sportsmen. But, referring again to the Klamath River experiments, we see that fish planted 160 to 196 miles above the mouth of that river must have traveled at least those distances from the point of liberation, inasmuch as they spent one or more seasons at sea, *even if they did not leave the neighborhood of the river mouth*, and that they returned with great accuracy to the particular streams in which they were liberated. To return to these streams these fish had to make a choice between numerous tributaries, many of which were larger than the streams in which they were planted. These experiments alone seem to provide direct evidence of the existence of homing in salmonids.

Since the fish referred to made choices between tributaries with accuracy, it seems quite conceivable that they may also travel at least equal distances at sea, past the mouths of other streams, and still return to the river system which they left. Indeed, it would seem rather far-fetched to assume that the marked Scott Creek and Waddell Creek fish leaving their respective streams had remained within two miles of the stream mouth, but this they would have to do if their return were dependent only on their not leaving the zone of river influence or the place of marked gradient. One additional point is to be emphasized. Scott and Waddell creeks, and numerous other California streams in which there are salmon and steelhead runs, actually *do not have a zone of river influence* during the summer months of most years, for at that period sand bars form completely across the mouths and no fresh water escapes into the ocean. Consequently, *some factors other than reaction to river water must determine the movements of such fish at sea.*

Now, the writer's impression was that Dr. Huntsman had disputed this point and Taft and Shapovalov (1938) stated that he had advanced the theory "that a true homing instinct does not exist and that the fish return to their parent stream only when they do not leave the neighborhood of the river mouth and thus the influence of the fresh water from that stream." But Dr. Huntsman, in a letter of December 6, 1938, writes as follows: "You are mistaken in believing or stating that I have advanced the theory 'that a true homing instinct does not exist.' I merely affirm that the traditional conception of homing from *distant* places lacks definite proof."

Our fourth question is, "If it does exist, what is the mechanism by which it operates?" The writer does not believe that the answer to this question is yet clear. Some work has been carried out on the correlation of various environmental factors with the spawning and the upstream spawning migrations of salmon and trout. For example, Pritchard (1936) found that a significant positive correlation existed between the number of adult pink salmon (*Oncorhynchus gorbuscha*) migrating daily from the sea to the spawning areas in McClinton Creek, Masset Inlet, British Columbia, and both the maximum daily water height in the stream and the daily rainfall in the region. From available data Pritchard found no definite effect of changes in temperature in producing a run.

Krokhin and Krogius (1937) have studied the relation of various hydrochemical and hydrophysical conditions to the spawning areas of Pacific salmons in Kamchatka.

The writer wishes to emphasize that positive correlations between the spawning migrations of salmonids and various chemical and physical conditions in themselves *do not disprove the existence of homing or even of a homing instinct*. In the present state of our knowledge such conditions must be considered only as stimuli which possibly contribute to the starting and progress of the fish on their spawning migrations and aid them in traveling the correct route *to their home stream*, and not as stimuli which cause them to select a stream in which to spawn irrespective of whether it is their home stream or not.

Taft and Shapovalov (1938) said: "Just what it is that guides the fish in its return from the ocean to the river system which it left and then into its parent stream is an intriguing problem that has caused much discussion but is still unanswered."

Closely connected with the fourth question is the fifth, "If it does exist, what name should we properly assign to the phenomenon?" Some objections have been advanced to the use of the terms "instinct," homing," and "parent stream." The most serious objection that the writer can see to the use of the term "instinct" is the looseness with which it has been used by writers of biological literature generally and by popular writers and the public at large especially. But, if under such circumstances a word comes to have a vague meaning, the fault lies with those that have used the term incorrectly rather than with those that do use it correctly. If we are to use a different term we must be sure that the new term will be more specific and will convey our meaning more satisfactorily than the old one.

At least some modern biologists of recognized standing define "instinct" as follows, to quote two examples:

Michael F. Guyer, in his Animal Biology (Guyer, 1931), says:

> There is no hard and fast distinction between reflexes and instincts. In general where the inherited action-pattern is more complex than that involved in a simple direct stimulus and response, the reaction, particularly if more or less definitely directed toward a useful end, is usually regarded as an instinctive one.

C. R. Plunkett has a comprehensive discussion of instincts in his Elements of Modern Biology (Plunkett, 1934). To quote in part:

> In the higher animals—i.e., those with a central nervous system—while some stimuli may elicit only simple reflexes, involving the action of one small group of effectors, other stimuli initiate very complex series of responses, either simultaneous or successive. These compound reflexes are commonly called *instincts.*

And further:

> Whether the initial stimulus be external or internal, the essential nature of these complex instinctive actions is a chain of reflexes, each response constituting a stimulus which arouses the next response, and so on.

In view of these definitions, the writer feels that the homing of trout and salmon should be considered as a true and excellent example of *instinct.*

The objections to the terms "homing" and "parent stream" also do not seem valid to him. Unless we are dealing with living things *strictly* under laboratory or artificial conditions we must think of them under *natural* conditions, and under natural conditions salmon and trout *do* return to their home and to the stream of their parents. Is a homing pigeon no longer a homing pigeon if it is trained to return to a different loft from that in which it was reared or born? But, if we are to find technical objections to the use of the term "homing," we must object also to a whole series of terms used in scientific literature, quite clear in meaning but subject to dispute if we are to analyze the derivation and composition of the words.

The conclusion of the writer must necessarily be that anadromous forms of trout and salmon do return as spawning adults to the streams which they left as young fish, whether naturally or artificially propagated, and that it is proper to consider this return as being accomplished through the operation of a true homing instinct. It is probable that in some species of trout and salmon the homing instinct is not developed as strongly as in other species and possible that in some species of trout it is but feebly developed or does not exist at all. It is also possible that certain varieties, races, or subspecies of any given species of trout or salmon may have the homing instinct developed less strongly than other varieties, races, or subspecies of that species. There is also evidence indicating that in some years mass migrations of a given species, race, or "run" of spawning salmon from the sea to a stream or streams other than the home stream may take place. Such occurrences should perhaps be considered as bearing the same relation to the validity of the homing theory that mutations bear to the validity of the general laws of genetics.

It is true that much of the evidence in favor of the homing "theory" is, technically speaking, "circumstantial," in much the same manner that the evidence in favor of the evolution "theory" and many other biological phenomena is "circumstantial." But, when a chain of facts forms a mass of evidence that points in one direction, it seems only reasonable and justifiable to accept the conclusions to which this evidence leads. Far from being pointless to speak of a homing instinct unless "direct" evidence is presented, it seems much more pointless to attack the "homing theory," and consequently the conservation practices built around it, without a considerable amount of even "circumstantial" evidence to disprove it.

Finally, it may be not inapropos to add that the existence of homing in trout and salmon, however remarkable, is not altogether surprising in view of its widespread existence among other animals. It operates not only among highly developed vertebrates, such as birds, and probably many groups of fishes, but also among invertebrates, for example, among mollusks.

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A COMPARATIVE STUDY OF OREGON COASTAL LAKES FROM A FISH-MANAGEMENT STANDPOINT

By FRANCIS P. GRIFFITHS and ELDEN D. YEOMAN

SPORT FISHING has increased tremendously in recent years. Unfortunately there has been no increase in water areas available for fish production, and in many places there has been an actual decrease in fish production due to ecological changes brought about by changes in land use such as deforestation, agricultural development, and development of water uses such as power and irrigation. Attempts to meet the constantly increasing demand for fish by means of artificial production have been only partly successful and it is gradually being recognized that factual information is necessary as a basis for management and maximum use of fishery resources. As a part of its program of technical investigations, the Oregon State Game Commission in 1938 authorized a study of certain Oregon coastal lakes. The object of the study was to determine why certain lakes were not producing fish while others were, and to find, if possible, a lake which could be used as a brood lake for the production of coastal cutthroat trout (*S. clarkii clarkii*). This paper presents technical information and recommendations resulting from this survey.

Geographical features of the area in which the lakes are situated.—The lakes studied are situated in a narrow strip of land approximately six miles wide and thirty-six miles long, running north and south about midway of the Oregon coast. This strip of land is bounded on the west by the Pacific Ocean and on the east by foothills which merge into the Coast Mountains. A belt of low sand dunes extends along the western edge of the strip. The ground cover varies from none or low stands of scrub oak on the sand areas near the ocean to Douglas fir transition types in the foothills. The predominant tree of the eastern edge is Douglas fir. Much of this area has been logged and is now covered only by low stands of underbrush.

The soil of the western edge consists of pure sand. This is constantly shifting and moving with the strong coast winds and forms moving dunes, which in some places are encroaching on the lake areas. The sand belt merges into a poor type of sandy loam, which in turn changes to Melbourne soil, and then to mountain-type shale and rock. Adjacent to parts of a few of the lakes are humus and peat areas, but the main types of soil are sand, sandy loam, and Melbourne red clay. The lakes are all at a low altitude, topographical maps indicating elevations of from twenty to sixty feet above mean sea level.

Climatological features of the lakes.—The region in which the lakes are situated possesses a moderate climate which is very suitable for rapid and continuous fish growth. The highest surface-water temperature observed during this survey was 69° F., and the lowest was 44.6° F. From United States Department of Agriculture Weather Bureau records the mean minimum temperature for the part of Oregon west of the Cascades is 36° to 40° F., the mean maximum temperature is 65° to 70° F., and the mean annual temperature is 50° to 52° F. The following mean monthly temperatures of the Umpqua Weather Bureau Station are typical, as this station is about midway of the coastal area.

Water temperatures of the lakes often exceed the summer air temperatures by ten or twelve degrees F., due to heat adsorption from the sun, but winter temperatures are approximately those of the wind and rain. Frosts occur only occasionally in January.

Rainfall in this area is moderately heavy, the fifteen-year average, 1915–1930, being 59.16 inches per year. The distribution of rainfall is quite uneven, as shown in table 1.

TABLE 1

Mean Monthly Temperatures, 1921–1930, and Rainfall, 1915–1930, Umpqua Weather Bureau Station

Month	Degrees F.	Inches	Month	Degrees F.	Inches
January	44.5	9.32	July	57.1	0.66
February	47.0	8.86	August	58.4	0.74
March	48.0	6.96	September	57.4	1.94
April	50.0	4.35	October	54.8	3.50
May	52.6	3.09	November	50.3	9.26
June	55.9	1.23	December	45.5	9.24

The rainfall is sufficient to keep the larger streams from going dry, but in logged-off areas many of the smaller streams dry up completely in the late summer and fall.

The equitable climate of this area is largely due to strong northwestern winds blowing in from the ocean and acting as a cooling agent in the summer.

TABLE 2

Fish known to be Present in Each Lake

Fish	Lake									
	Tenmile	Eel	Woahink	Siltcoos	Mercer	Sutton	Collard	Clear	Aikerly	Munsel
Cutthroat trout *Salmo clarkii*	a	a	a	a	a	a	a	a	a	[illegible]
Silverside salmon *Oncorhynchus kisutch*	a	a	a	a	a	a	b	b	b	b
Large-mouthed bass *Aplites salmoides*				a	a	a	a	a	a	a
Yellow perch *Perca flavescens*				a						
Black crappie *Pomoxis sparoides*				a	a	a	a	a	a	a
Bluegill *Helioperca incisor*					a		a	a	a	a
Catfish *Ameiurus nebulosus*	a	c			b					
Grayling *Thymallus montanus*			c							
Loch Leven *Salmo trutta*	a									
Oregon pike *Ptychocheilus oregonensis*			a	a						
Steelhead or Rainbow *Salmo gairdnerii gairdnerii*	b		c	b	c					c
Suckers Catostomidae			a	a						
Stickleback Gasterosteidae	a	a	a	a	a	a	a	a	a	a
Red-sided shiner or Bream *Richardsonius balteatus balteatus*			a							

[a] Occurrence common.
[b] Occurrence rare
[c] Planted but not established.
[d] Planted in 1938, establishment uncertain.

These northwest winds blow from March to October, inclusive. During November, December, January, and February the prevailing winds are from the southwest.

Fishes present.—The lakes of this area originally contained only a few species of fishes. The game fish most abundant are silver salmon (*Oncorhynchus kisutch*) and coastal cutthroat trout (*Salmo clarkii clarkii*). All the larger lakes are connected with the ocean by short streams and fall runs of these two species supplement lake production. With the settlement and development of this region other species of game fish have been introduced in many of the lakes. Those introduced include large-mouthed bass, small-mouthed bass, calico bass, white crappie, perch, bluegill sunfish, and catfish. Shad and striped bass have in recent years become numerous in the sea area adjacent to these outlets. The introduced fish are doing well in the shallower, more productive lakes. Table 2 lists the lakes with the main species found in them. The effect of spiny-rayed fish on native fishes will be discussed under limiting factor.

Limnology of the lakes.—It is not the intention of this paper to present a very detailed account of the limnology of these waters, but rather to point out certain general features and important differences. The lakes vary in size from about 10 acres to more than 3000 acres in area. A comparison of sizes is best afforded by means of table 3. The form of the lakes varies from oval to so irregular as to make a general description difficult. The long axis of many of the lakes lies in a north–south direction. This permits wind action to be particularly effective in producing water overturn and wave action.

The shore line varies from pure sand and hardpan on the low-producing lakes to muck and silt around a large part of the more productive lakes. Equally significant differences are noted in the character of the bottoms in the different lakes. Low production is always associated with sandy bottoms. The most significant morphological feature of these lakes influencing productivity is that of depth. Wherever the depth of the lake is greater than the depth of the epilimnion and temperature transition zone, there occurs an oxygenless zone which effectively blankets the bottom of the lake. In the shallower lakes, those less than thirty feet in depth, wind action usually prevents summer stratification, and as a result the entire lake bottom is available as a food-producing unit. This is especially noticeable of Tenmile and Siltcoos lakes.

TABLE 3

WEIGHT OF BOTTOM SAMPLES, ACREAGE, AND FOOD PRODUCTION

Lake	No. of samples	Wet weight of organisms			
		Grams per sq. ft.	Pounds per acre	Total acres	Total pounds of bottom organisms
Mercer	8	2.223	213	320	68,160
Munsel	4	1.500	144	120	17,280
Tenmile	4	1.470	141	1,170	164,970
Siltcoos	6	1.260	121	3,116	377,036
Sutton	2	1.020	98	120	11,760
Clear	4	1.000	96	160	15,360
Collard	4	.780	75	60	4,500
Aikerly	4	.690	66	10	660
Eel	9	.600	58	370	21,460
Woahink	10	.220	21.1	820	1,730

These large, shallow lakes are typical of eutrophic lakes in having a low average depth, practically no hypolimnion, and a higher productivity than the other water areas. Form of the lake and wind action have a marked influence on the depth at which thermal stratification occurs. In Collard Lake, a small, well-protected lake, a thermocline was evident at a depth of 27 feet (October 17), whereas, in the large, more exposed Woahink Lake the thermocline began at 51 feet (October 8).

A portable chemical kit was used to determine dissolved oxygen and methyl orange alkalinity of the lakes. Several water samples were sent to Dr. Ellis for

TABLE 4

Data on Parts per Million of Oxygen and Methyl Orange Alkalinity of Oregon Coast Lakes

OXYGEN								
Lake	Date	Surf.	20′					
Tenmile........	8/3	8.7						
Tenmile........	9/3	8.8	8.7					
			28′	33′	36′	39′		
Mercer.........	10/11	11.2	11.1	0.0	0.0	0.0		
Mercer.........	10/19	9.5		8.4	4.1	0.0		
Mercer.........	12/27	10.5		10.5	10.5	10.5		
			42′	51′	63′	72′		
Woahink........	8/16	10.0						
Woahink........	9/3	10.4	9.9	8.8	3.8	2.0		
Woahink........	10/8	10.9		9.2	1.4	0.7		
Woahink........	10/27	11.5				10.6		
			39′	42′	51′	66′	70′	
Eel............	10/14	9.9	8.1	0.9	0.7	0.1	0.0	
Eel............	12/30	11.1					10.1	
			21′	24′	27′	30′	33′	36′
Collard.........	9/2	10.5	7.3	0.8	0.0			
Collard.........	10/20	9.7			9.5	9.1	1.4	0.7
			30′	33′	39′	46′		
Aikerly.........	10/20	9.1	8.3	1.7	0.1	0.0		
			30′	39′	75′			
Munsel.........	10/20	10.9	9.6	3.0	0.0			
			43′	61′	79′			
Clear...........	9/2	10.5	10.5	1.5	1.0			
			18′	21′	31′			
Sutton..........	10/11	10.0	9.5	7.8	0.2			
			12′					
Siltcoos........	10/9	10.1	10.6					

TABLE 4—(*Continued*)

METHYL ORANGE ALKALINITY

Lake	Date	Surf.	20′					
Tenmile	8/3	21.0						
Tenmile	9/3	26.0	26.0					
			28′	33′	36′	39′	42′	
Mercer	10/11	16.0	16.0			47.5	B	
Mercer	10/19	17.0	17.5		26.5	54.5	B	
Mercer	12/27	13.5				18.0	B	
			51′	63′	72′			
Woahink	8/16	9.0						
Woahink	9/3			10.0	11.0			
Woahink	10/8	9.0	11.5	11.5	11.5			
Woahink	10/27	10.0			11.5			
			39′	42′	51′	66′	70′	
Eel	10/14	13.5	14.5	19.5	22.5	29.0		
Eel	12/30	12.5					15.5	
			10′	27′	30′	33′	36′	
Collard	9/2		14.0		35.0			
Collard	10/20	12.0		13.5		13.5	14.5	
			30′	33′	39′	46′		
Aikerly	10/20	13.0	14.0	19.5	40.5	99.0		
			30′	39′	75′			
Munsel	10/20	13.0	13.0	15.0	41.0			
Clear	9/2	14.0						
			21′	31′				
Sutton	10/11	15.0	19.0	62.0				
			12′					
Siltcoos	10/9	22.0	23.5					

more complete analysis. Oxygen tests showed a very pronounced decline in the oxygen level below the level at which the wind actuated overturn or mixing ceased. As the temperature of the surface water decreased and winter conditions became more pronounced, both the thermocline and the oxygenless zone approached the bottom and finally disappeared altogether.

Methyl orange alkalinity is really a measure of the buffer capacity of the waters, and as such is significant in indicating the amount of dissolved salts in the water. Experience has indicated a consistent correlation between high buffer capacity and biological productivity in other Oregon lakes. The coastal lakes are uniformly low in methyl orange alkalinity. The water of this entire region is extremely soft and the lakes reflect the lack of soluble mineral substances in the soil. It is significant that the two richest lakes, Tenmile and

Siltcoos, have the highest methyl orange alkalinity observed in oxygenated waters. A sharp rise in methyl orange alkalinity in the bottom waters of several lakes having stagnant zones indicates the occurrence of mineral stratification. Table 4 lists these data.

Food supply of the lakes.—Fish were taken by means of sampling nets and by hook and line. Bottom samples were made with an Eckman dredge. The analysis of the food found in the stomachs of the fish is believed to be a better index of available food than bottom samples, but bottom samples offer a more convenient means of comparing relative productivity of the lakes themselves. No quantitative measurements of plankton were made, although plankton tows were made in all the lakes and relative abundance was noted. Table 4 presents the weight and poundage production of bottom organisms in the lakes.

Chironomus larvae and Corethra larvae were most numerous in the bottom samples. The percentage occurrence according to numbers counted was: *Corethra,* 54 per cent; *Chironomus,* 39 per cent; *Asellus,* 6 per cent; *Hexagenia* nymphs, 1 per cent; Sialidae larvae, 1 per cent. Stomach analyses indicate that in the poorer lakes the fish fed on surface food and depended on catching smaller fish to a much greater degree than did fish in lakes having more aquatic organisms. Table 5, presenting a comparison of the food eaten by the fish

TABLE 5
FOOD OF CUTTHROAT TROUT IN OREGON COAST LAKES

Food	Lake							
	Woahink	Eel	Siltcoos	Sutton	Munsel	Tenmile	Mercer	Total
Number of stomachs	5	8	2	3	1	22	3	44
Red termites	63	1				23		87
Black termites *Reticulitermes lavipes*	20	1118						1138
Sticklebacks Gasterosteidae sp.	8	3				1		12
Bullheads *Cottus* sp.	4	3				1		8
Mysis relicta		43				594		637
Snails *Goniobasis*	2	1				6		9
Leafhoppers Cicadellidae	7					1		8
Water mites *Hydracarina*	1					10		11
Mayfly adults *Hexagenia*			7		2			9
Mayfly nymphs *Hexagenia*		1	24		7	3	17	52
Midge larvae *Chironomus*	3		1			47		51
Midge larvae *Corethra*				602		98	131	831
Water sowbug *Asellus*						58		58
Flying ants Formicidae						59		59
Caddis flies *Trichoptera*							5	5

caught from Woahink Lake and Eel Lake with those caught in Tenmile Lake, is interesting in this respect. Stomachs from fish during the winter when land insect forms are not available would be of especial interest.

A number of fish taken during the summer by means of sampling nets were weighed and measured and their condition factors determined according to the equation

$$\text{CF} = \frac{(\text{Wt. in lb.})\ (100{,}000)}{\text{St. length in inches}}$$

The condition factor for six cutthroats caught in Woahink averaged 50.4; Eel Lake, 8 cutthroat, 53.4; Tenmile, 14 cutthroat, 53.3; Siltcoos, 2 cutthroat, 50.9; Sutton, 2 cutthroat, 48.8; Mercer, 3 cutthroat, 48.9. It is of interest to note that there does not seem to be a correlation between the average condition factor of the fish caught in the poorly producing lakes, Woahink and Eel lakes, and food abundance as compared with the richer lakes, Tenmile, Sutton, Mercer, and Siltcoos. Probably the lack in numbers of fish in Woahink and Eel lakes permitted sufficient food to accumulate for each individual. The average condition factor for cutthroats from all the lakes was 52.4. The average condition factor of five silver salmon yearlings 5 to 8 inches long from Woahink Lake was 50.9.

Limiting factors in lakes.—One of the most apparent limiting factors of these lakes is the decline or lack of spawning streams tributary to the lakes. On streams tributary to Tenmile and Eel lakes, deforestation has caused many of the smaller streams to become so seasonal as to dry up completely in summer. Other streams greatly decrease in volume and many small fish are lost in temporary pools or through predators. There are no spawning streams tributary to Collard, Aikerly, Munsel, or Clear lakes. Woahink Lake has one fair small spawning stream. Mercer and Sutton each have one fairly good spawning tributary. Siltcoos is most fortunate in having one excellent large stream as well as several smaller streams.

Lack of food is a decidedly limiting factor in Woahink Lake. During summer stratification periods, food shortage would limit production in Collard, Aikerly, Munsel, and Clear lakes, should the fish population be markedly increased. Deeper portions of Mercer and Eel lakes are also blanketed by an oxygenless zone during late summer and fall. Table 3 presents the oxygen decline and methyl orange alkalinities found during the fall and winter. Stratification disappeared from Woahink during the last of October, and during December and January from the other lakes.

Another limiting factor which we are at present unable to evaluate is competition between native and introduced species of fish. Perch, crappie, and bass are numerous in Siltcoos Lake and afford excellent fishing. According to all reports, trout fishing has consistently declined and it is reasonable to believe that one of the reasons for this decline is predation on the young by these fish. In Tenmile Lake, catfish have been introduced and have become extremely numerous. These catfish are considered competitors for food and as possible carriers of disease. Large-mouthed bass are caught in Sutton and Mercer lakes and are most abundant in Mercer Lake in the area around the mouth of the best spawning stream. Another large lake, Tahkenitch Lake, has both large- and small-mouthed bass as well as crappie, perch, and sunfish, and again salmonoid fishing is reported as having markedly decreased.

Angling on the coastal lakes has been intense and represents a serious depleting factor. Of the lakes investigated, Tenmile has the best fishing for trout and silver salmon and Siltcoos has the best fishing for spiny-rayed fish. Mercer Lake and Sutton Lake were formerly excellent trout lakes, but in recent years fishing has not been particularly good. Present game laws permit fishing for

TABLE 6

Condition Factor of Cutthroat Trout Caught in Oregon Coast Lakes

Locality of catch	Date of catch	Standard length (in.)	Weight (lb.)	Condition factor
CUTTHROAT TROUT				
Woahink Lake	9/27	8.62	.32	49.87
		9.12	.35	46.06
		10.00	.53	53.00
		7.50	.24	56.89
		8.87	.32	45.78
	12/29	13.25	1.19	51.02
Eel Lake	8/9	6.37	.14	54.05
	10/3	5.75	.11	57.86
		10.25	.62	57.58
		8.00	.28	54.69
		6.50	.14	50.98
		7.50	.21	49.78
		6.62	.16	55.06
	8/9	14.00	1.30	47.37
Tenmile Lake	8/5	6.00	.09	41.67
		8.37	.29	49.37
		6.87	.18	55.39
		7.00	.16	46.65
		6.75	.18	58.53
		6.50	.16	58.26
		6.37	.18	69.47
		6.25	.14	57.34
	9/2	5.25	.08	54.04
		6.25	.11	45.06
		8.37	.27	46.82
		8.25	.28	49.87
		8.25	.26	46.30
	8/6	16.75	3.19	67.88
Siltcoos Lake	8/18	8.62	.33	51.46
		8.50	.31	50.48
Sutton Lake	8/20	9.12	.44	48.22
		9.12	.45	49.39
Mercer Lake	12/29	9.50	.44	51.79
		8.75	.34	51.35
		8.50	.27	43.75
SILVERSIDE SALMON				
Woahink Lake	12/29	8.25	.27	48.98
		8.12	.26	48.94
		7.87	.26	52.48
		6.87	.16	48.10
		5.25	.07	47.55
Sutton Lake	8/20	6.62	.17	58.46

trout over ten inches in length throughout the entire year in Sutton, Mercer, Tenmile, Siltcoos, and Woahink lakes. This has effectively reduced the basic spawning stock, especially the sea-run fish which enter these lakes from the ocean after the fall rains start. Fishing for trout over six inches in length is permitted in all the lakes from April 15 to October 15. Bass, perch, and crappie and catfish may be taken throughout the year.

The effect of angling in reducing the spawning stock was effectively illustrated by a tagging experiment carried on in North and South Tenmile lakes. Two hundred adult native cutthroats were tagged during their winter spawning migration. Several tags were returned previous to the regular trout season and to date 17 tags have been reported. This represents a decline of 8.5 per cent in adult spawning stock in a period of approximately six months. Reported with four of the tags were 177 untagged fish, or an estimated take of 751 fish on the basis of the 17 tags returned. Since the voluntary return of tags is known to be incomplete, it is evident that the angling intensity is quite high. Formerly the streams connecting these lakes with the ocean were also open to fishing.

Parasites and diseases offer an important unsolved problem in relation to fisheries management. The majority of native fishes in the coastal area of Oregon have parasites. Parasites found in the examination of fish from Woahink Lake are *Philometra oncorhynchii,* a viviparous roundworm occurring in the body cavity of trout and salmon; *Dibothrium* sp., a cestode found in the stomach wall and viscera; and *Diastoma* sp., a fluke found in the intestines. Of almost universal occurrence is the encysted cercariae of the salmon poisoning fluke, *Nanophyetus salmincola.*

Losses of fish have been reported from Woahink Lake and several trout have been found which were apparently dying of parasitic infestations. One theory proposed to explain the failure of eastern brook and black-spotted (Montana cutthroat) trout to survive in western Oregon is that they are more susceptible to indigenous diseases than are native fish.

Management of the lakes.—Fish management is admittedly in its infancy. One thing that should be recognized is that absentee treatment is not effective. A continuous program of study and management involves considerably more manpower than is now available. On the basis of what has been learned about these lakes certain suggestions concerning what to do and what not to do can be made.

Siltcoos Lake has already a dominant stocking of spiny-rayed fish. This lake is providing excellent fishing for a large number of anglers. Further study on this lake may indicate the desirability of introducing a forage fish such as the blunt-nose minnow. The danger in such a procedure is that sportsmen are apt to transfer the introduced fish into waters where its presence is not desired. Planting of trout and salmon in this lake is not considered an economical practice. Aikerly, Collard, Clear, and Munsel lakes present something of a problem. Vegetation is not abundant, shore production is very low, and the deeper bottom areas are covered by an oxygenless zone. A few bass are now present in these lakes, and it is not felt that additional stocking would be profitable.

Management practices can best be applied to those lakes which are primarily useful for trout and salmon. These are Sutton and Mercer lakes, Woahink Lake, Eel Lake, and Tenmile Lake. It is recommended that the program include the following main points:

1) No plantings of spiny-rayed fish or nonnative fish in these lakes, and a definite effort to remove the bass now present in Sutton and Mercer lakes.

2) Supervised plantings of native cutthroat trout and silver salmon. Super-

vision includes the determination of the number and size to plant, the proper time of planting, and the results from such plants.

3) Encouragement of sea-run fish. The sea run of cutthroat and silver salmon offers a means of tremendously increasing the productivity of these water areas. Instead of attempting to restrain the fish by means of screens, efforts should be concentrated on building up the runs to approach their former magnitude.

4) Closure of winter fishing. Although there is a dearth of factual information on the amount of fish removed by fall fishing, all information points to the conclusion that the removal of many fish while on their way to spawn is a serious factor in depleting the runs. A permanent closure is not contemplated, but a temporary closure for several seasons is necessary.

5) Protection of spawning areas. This involves the improvement of spawning areas on Woahink and Eel lakes, the patrol of the streams and protection of the fish during the main spawning season, and provision for maximum use of the spawning streams. At present, spawning racks for both silver salmon and cutthroat trout block the best spawning stream on North Tenmile Lake, and another rack is occasionally used on a stream tributary to South Tenmile Lake. It is decidedly desirable that some provision be made to insure adequate use of the spawning areas above the racks in order that egg-taking operations and artificial propagation be supplementary to, rather than competitive with, natural reproduction. Preferably one-half, and at least one-third, of all the fish reaching the racks should be permitted to spawn naturally. Protection should also involve the patrol of streams during the late spring to prevent the losses occasioned by declining water levels.

6) Development of a brood lake and special studies on problem lakes. As a result of this survey, the Game Commission will acquire Eel Lake. This lake at present has little recreational use and is at a low point in fish productivity. It is believed that by proper stocking, protection, and management a run of cutthroat may be built up which will not only maintain this lake, but will also afford a source of eggs for hatchery use.

Heavy recreational use warrants the consideration of certain lakes as problem lakes deserving special attention. Woahink Lake is one of these. Previous to this year, plantings of fish in this lake have not produced tangible results. Records of plantings since 1935 are: 1935, 100,000 steelhead; 1936, 95,000 steelhead; 1937, 50,000 cutthroat and 250,000 grayling; 1938, no fish. Fishing remained extremely poor, and so this spring an experimental plant of cutthroat trout averaging about eight inches in size was made. This season's returns are not complete, but the results to date are of considerable interest.

In March 1939, 2500 seven- to eight-inch trout from the Bandon Hatchery were tagged with a special monel metal tail tag having a serial number and the lettering, "Notify Ore Game Comm." Twenty-seven tags were recovered before the fish were liberated, owing to injury to the fish or faulty placement of the tags. In addition to the 2473 tagged fish, 1205 untagged fish were liberated about three weeks previous to April 15. For two weeks subsequent to the season's opening, anglers' catches were checked on the lake. During this period 72 game fish were caught; of these, 38 were tagged, 14 additional fish were from those liberated but not tagged, 13 fish were native cutthroats, and 7 were young silver salmon.

We now have a record of 847 fish caught from this lake this season. Of these, 369, or 44 per cent, were tagged fish, 340 were trout not tagged, and 138 were reported as silver salmon. On the basis of the catch record, 545, or 64.3 per cent, of the catch are believed to have resulted from the 3678 fish liberated and 302 fish from native stock. The return of 14.9 per cent of tagged fish liberated represents one of the highest yields from artificial stocking of which we have a record. Such a planting as was made here is obviously impossible except in special instances, but it does serve to illustrate the possibilities of such a method.

Certain of the low-producing lakes in this area offer very interesting possibilities for experimental work on lake fertilization. It is our belief that lake fertilization of water areas not having too heavy a run-off might provide an increased production of plankton and vegetation to such an extent as to be a very profitable method of lake improvement. We hope to be able to make several such experiments.

Conclusion.—The results reported in this paper represent an initial effort to determine biological conditions and differences existing in a series of Oregon coastal lakes. It is hoped that, as studies progress, more data and management methods of definite value will result.

[Oregon Agricultural Experiment Station Technical Paper No. 316]

NOTES ON THE NATURAL SPAWNING OF CUTTHROAT TROUT (SALMO CLARKII CLARKII) IN OREGON

By Frederick K. Cramer

The following study of the cutthroat trout was carried on at the Alsea Trout Hatchery and on the north fork of the Alsea River of Oregon and on Bailey Creek, a small stream entering the north fork of the Alsea River near the hatchery, during January and February, 1939. The characteristics and habits of the cutthroat may be appreciably different in other environments.

The study was concerned primarily with the natural spawning activities relating to time of spawning, percentage of live eggs among eggs recovered from nests, number of eggs per female, length–weight relationships, and sex ratio.

Results and data gathered cannot be considered by any means to answer adequately and completely the questions raised. More experiments and observations are necessary, not only to learn additional facts about the cutthroat trout, but also to check the results obtained in this study.

However, the results obtained are an addition to what is known about the cutthroat trout and, it is hoped, will be a step toward a more complete knowledge of the habits of this important game fish.

For help in this study the author wishes to thank Mr. Matt Ryckman, Oregon State Game Commission, who granted permission to carry on these studies at the Alsea Trout Hatchery; Mr. G. C. Webb, Superintendent, and Mr. J. W. Jarvis, Assistant Superintendent, Alsea Trout Hatchery, who offered important suggestions and practical aid; and Professor R. E. Dimick and Dr. Francis P. Griffiths, Oregon State College, who suggested new problems from time to time.

Natural Spawning

Time of spawning.—About one-quarter mile upstream from the Alsea Trout Hatchery is a dam with a fish ladder on one side leading into a trap. The fish trapped supply cutthroat eggs for the hatchery.

The number of cutthroat trout and the date at which they were taken from the trap on their upstream migrations are as follows (data taken from hatchery records of number of cutthroat taken from trap):

December 5, 1938	82	January 20, 1939	4
December 9, 1938	39	January 31, 1939	1
December 30, 1938	31	February 9, 1939	2
January 6, 1939	19	February 17, 1939	2
January 13, 1939	7		

These figures indicate that the height of the upstream spawning migration occurs in late November and early December, with a gradual decline beginning in mid-December and becoming more abrupt after the first week in January. Since December 5 was the first date cutthroat were taken from the trap, the migration preceding that date is not known, but probably preceded it by not more than a week or ten days.

Although a few cutthroat may spawn in this area as late as March and even April, by far the greater number probably spawn in late December, January, and February.

Although bottom conditions were suitable in many parts of the main river, nests were much more numerous in the smaller tributary streams than in the main stream, the north fork of the Alsea.

Time of hatching.—Assuming that the eggs will hatch in from 45 to 50 days, most of the eggs would probably hatch from about the middle of February until the middle of April. A few will hatch later than the main group.

Nature of gravel beds and nests.—On January 25 a cutthroat nest was found on Bailey Creek. This nest was about 2 feet long and 1½ feet wide. The largest gravel composing the nest was found on top and was roughly the size of a walnut. The eggs were found in much smaller gravel, about the size of a pea, and in very coarse sand, at the bottom of the nest at a depth of 5 to 7 inches from the top of the nest. The water in which the nest was situated was about 7 inches deep and quite swift.

In one of the wire-screened pens constructed for natural spawning experiments, a female made two nests in an area of gravel 4 feet long and 2 feet wide. When these nests were dug up, by far the greatest number of eggs were found at one level, from 4 to 5 inches below the top of the nest.

In three other nests that were dug up the eggs were found at about the same level, from 4 to 6 inches from the top of the nest, in pea-sized gravel and in very coarse sand, the gravel at the top of the nest being much larger, even to the size of a walnut.

Spawning Activity.—The female does all the work of nest building. She will swim lazily back and forth over the gravel, and then stop suddenly and turn over on her side and, with arching, scraping movements of her tail, scoop out the gravel to form a nest.

On the afternoon of February 4 a female cutthroat was seen engaged in nest building. When first observed, she had built a nest about 4 inches deep, 20 inches wide, and about 22 inches long on the outside, tapering down conically in the center, which was the deepest part. With a male, she was first seen at 1:50 P.M. At 2:00 P.M. she stopped digging and rested on the gravel, the male remaining behind her and to her right, his head about even with her dorsal fin. They remained in this position for 15 minutes, and then turned and swam back into a deeper pool. At 3:15 P.M. they were still in the deeper pool and had not returned to the riffle and gravel bar.

I believe that actual spawning takes place both at night and in the daytime. Cutthroat were seen spawning in the daytime on several occasions. Nest building was observed one evening from 7:30 to 9:00 o'clock, and spawning also probably occurred at night.

Trout placed in the spawning pens always finished spawning within two days after they were placed there. One female spawned all her eggs, none being left in her upon later examination; and 521 of her eggs were recovered from her nest. Another female had 67 eggs left in her after spawning, 414 being recovered from her nest. Possibly she had not completed spawning when the eggs were counted.

In the only experiment tried, the female did not engage in nest building when the male was not present. At 1:40 P.M., Tuesday, January 31, a female cutthroat was placed in one of the spawning pens. No male was put in with her. At 4:30 P.M., Friday, February 3, no action had been taken by her in nest building. At this time a male was placed with her and at 9:30 the next morning, Saturday, she was busily engaged in completing the building of a nest.

In actual spawning, the male discharges his milt simultaneously with the discharge of eggs by the female, the female being settled down in the pit of the nest. The male is in close contact with the female at this time, so that the milt may envelope and fertilize the eggs. After laying the eggs, the female goes upstream perhaps a foot and a half to two feet and digs another nest. The gravel dislodged by her tail is carried downward by the current and covers the eggs of the preceding nest. Milt from the male was once seen clouding the water, although the actual discharge of eggs from the vent was not discernible.

Fertile and dead eggs removed from nests.—Removals were observed as follows:

1. On January 25 a cutthroat nest was found on Bailey Creek. This nest was dug up and 35 eggs were removed. Of the 35 eggs removed, 1 was dead, giving a percentage of live eggs in this sample of 97.14 per cent. These eggs were not more than one week old.
2. On February 17 a nest in the spawning pens was dug up. A total of 388 eggs were recovered from this nest. These eggs were 29 days old, well eyed, and came from a hatchery-reared female. Of the 388 eggs removed from the nest, 29 were dead, giving a percentage of fertile eggs in the sample of 92.5 per cent. Of the 29 dead eggs, 5 died after reaching the eyed stage, 6 were not fertilized at all, and 18 were fertilized but died before reaching the eyed stage. It is well known, from hatchery records, that after reaching the eyed stage the eggs are hardier and less susceptible to death from natural causes.
3. On January 30 a nest in the spawning pens was dug up and 414 eggs removed. Of these, 8 were dead, giving a percentage of fertile eggs in this sample of 98.06 per cent or, conversely, a mortality of 1.94 per cent. These eggs were 13 days old.
4. On February 24 a nest in the spawning pens was dug up. A total of 521 eggs were recovered. Of the 521, 36 were dead, giving a percentage of fertile eggs in this sample of 93 per cent. These eggs had been in the gravel for 17 days but were not yet eyed. The female laid these eggs in a period of two days. She spawned completely, later examination showing no eggs left in her.

The dead eggs were not badly decayed. They were of nearly the size of the live eggs, but white in color and soft. In all the above-described trials except the second no differentiation was made between eggs not fertile and eggs fertilized by dying later. The ratio was between infertile plus dead eggs and the live eggs. In the second trial the white eggs were cleared by a salt solution to a degree permitting us to distinguish between infertile eggs and those fertilized but dying later.

The results of these tests show that the percentage of fertile live eggs among the samples recovered from the nests at various stages in development seems to be quite high—90 per cent and better.

EGG COUNTS

Egg counts of hatchery-reared trout just about two years old are as follows:

Standard length (cm.)	Total length (cm.)	Eggs (No.)
23.1	....	416
....	25.8	403
24.0	....	467
....	26.5	226
21.5	....	438
20.7	....	285
		Average....372.5 eggs per fish

The two low figures of 226 and 285 eggs are very probably much below the average. A better average would be in the neighborhood of 430 to 450 eggs per fish.

Egg counts of wild cutthroat are as follows:

SMALLER RESIDENT CUTTHROAT

Standard length (cm.)	Total length (cm.)	Eggs (No.)
26.0	28.5	380
23.1	25.8	415
29.0	32.3	615
....	....	521
....	....	467
	Average....	480 eggs per fish

LARGE SEA-RUN CUTTHROAT

Standard length (cm.)	Total length (cm.)	Eggs (No.)
30.5	39.5	1,098
38.5	44.0	1,242
	Average....	1,170 eggs per fish

Eggs from hatchery-reared trout were lighter in color than those from the wild fish.

Sex Ratio

Out of 257 cutthroat counted at random during the spawning operations, 135 were males and 122 were females. This gives a 52:48 sex ratio, with males predominant. A much larger number should be sampled to get a true indication of the sex ratio.

TABLE 1
Weight–Length Relationships

Standard length	Total length	Weight	Condition factor*	Sex
(in.)	(in.)	(oz.)		
13½	14½	13	33.02	Female
13¼	14¼	10	27.02	Male
10½	11½	5½	29.69	Female
8½	9¼	2¼	22.90	Female
8¼	8½	2	22.26	Female
8¼	8½	2	22.26	Female
11	11½	6	28.17	Male
9½	10	4½	32.80	Female
7½	8	2	29.63	Female
9	9½	3½	30.01	Female
7¼	7½	1½	24.60	Female

	Average S. L.	Average weight	Average condition factor
Female..................	9.25 in.	4.1 oz.	27.46
Male....................	12.12	8.0	27.6

(The figures just given are taken from notes of Willard Jarvis. Fish caught on north fork of Alsea River, May 25 and 26, 1938)

Standard length	Total length	Weight	Condition factor	Sex
(in.)	(in.)	(oz.)		
10.23	11.22	8½	49.57	Female
9.84	10.32	6¼	42.62	Male
14.37	15.55	19½	41.07	Female
8.26	8.85	4	44.23	Female (no eggs)
15.55	17.32	33	54.85	Male
15.35	16.93	....	.....	Female
11.41	12.71	11½	48.39	Female (ten days after spawning)

(The wild or sea-run cutthroat were all taken on the north fork of the Alsea River in January and February, 1939)

	Average S.L.	Average weight	Condition factor
Females with eggs.......	12.28 in.	14.12 oz.	47.65
Females after spawning...	10.19	7.62	44.89

* The condition factor "is found by dividing the weight in pounds by the length in inches cubed and multiplying the result by 100,000."—Surber, "A Quantitative Study of Rainbow Trout," *Am. Fish. Soc.*, 1933, p. 254. (Standard length used in present calculations.)

The figures showing the variation in condition factor between females with eggs and females after spawning were derived from measurements taken from trout that were used in the wire-screened spawning pens.

In the figures given in table 1, weight per centimeter of length before spawning is 0.45 oz.; weight per centimeter of length after spawning, 0.29 oz. The figures show a 36 per cent weight loss after spawning. Of course this loss cannot be considered accurate, as only two conditions are considered for each of the classes: before spawning, and after spawning. However, it is plain that the condition factor is lower after spawning. Most of this reduction in condition factor is due to the loss of eggs, which shows that condition factors, to be comparable, should be taken on trout which are all in the same stage of sexual development.

THE BROWN TROUT ON VANCOUVER ISLAND

By Ferris Neave and G. C. Carl

In response to repeated requests by anglers for the introduction of brown trout to Vancouver Island, plantings of this species were made in 1932, 1933, 1934, and 1935 in the Cowichan and Little Qualicum river systems. These both flow to the east coast of Vancouver Island. The Cowichan River flows for 28 miles from Cowichan Lake (length, 21 miles) to the sea. Both lake and river receive numerous small tributaries. The Little Qualicum River is eight miles in length. Both river systems already contained cutthroat and rainbow trout as well as other salmonids. A total of 20,275 fry and 234,858 fingerlings and yearlings was planted at various points in the Cowichan River and Cowichan Lake, and 163,786 fry and 123,577 fingerlings and yearlings were planted in the Little Qualicum and tributaries.

It was hoped by those desiring the introductions that the brown trout would provide good fly fishing, particularly in summer, when angling for native species is relatively poor.

The following account is a summary of existing knowledge concerning the subsequent history of these plantings. Information on the brown trout in the Little Qualicum system has been supplied by Mr. A. Higgs of the British Columbia Game Department.

Cowichan River System

Spawning run of 1937.—A spawning run was first observed in detail in the early part of the winter of 1937–38, when ripe fish were taken in traps on two small streams tributary to the Cowichan River. The first fish appeared in the second week in November, and spawning fish continued to arrive at intervals throughout the following month in company with coho salmon, which were running at the same time. While it is probable that spawning in the Cowichan river system takes place mainly in winter, ripe fish have been taken earlier and also at intervals throughout the spring.

During the time of the spawning run the temperature of the main river dropped from a maximum of 12°5 C. to 7°6 C., while the temperature of the stream decreased from 7°5 C. to 6°5 C. Freshets appeared to have a major influence on the time of the run, since most of the fish appeared in the traps at times of temporary high water.

The ripe fish taken in the tributary streams totaled 36, of which 22 were females and 14 males. The total lengths varied from 15 to 22½ inches, the average being 16½ inches. Weights ranged from 1¼ pound to 4 pounds. Larger specimens which were not weighed may have exceeded 5 pounds. Of 26 fish examined, 11 were apparently in their sixth year, 12 in their fifth year, and 3 in their fourth year, as determined by scale readings. No indication of previous spawning was observed in any of the scales examined.

The parent fish, particularly the males, were brightly colored, a golden background being the most conspicuous feature. The knobbed lower jaw and strongly developed teeth, which are characteristic of other trout of the genus *Salmo,* were also present in the males. In most individuals of this sex, scale absorption had progressed to such a degree that it was difficult to obtain scale samples. Females were much lighter in color and lacked the extreme jaw development of the males. A number of fish of both sexes bore wounds, some of which were so much infected with fungus that it seemed unlikely the fish would survive the spawning run. This surmise was later confirmed by the finding of several dead, spent fish above the fence.

During the 1937 spawning run 24,250 eggs were taken by hand stripping twelve females (including one taken from the main river), the maximum yield per fish being 3623, the minimum 587, and the average 2020. From one trout 17½ inches in total length 1622 eggs were taken by body incision. In size the eggs seemed to be fairly uniform, averaging about 190 to the fluid ounce. In color the ova were a light amber, permitting them to be readily distinguished from other trout eggs, which are normally pink or orange in color.

Although a large proportion of the available eggs were thus removed to the hatchery, young fish of the year, the result of natural spawning, were found in one of the above-mentioned streams in October, 1938. During the spring of 1939 a fine-screen trap was operated on this stream, near its mouth, so as to intercept any fish moving downstream, and 107 young brown trout were taken in the trap between April 3 and June 6. Most of these were one-year-old fish. A few were two years old.

Spawning run of 1938.—In 1938, 31 fish passed through the traps on the two streams between October 31 and December 31, with a possibility that a few went upstream subsequently at a time when one of the fences was not in operation. There appeared, however, to be fewer large ripe fish than in the run of the previous year. No eggs were collected in this season. Scales showed that some of the fish in this run had spawned the previous year, while one male had apparently spawned in the winter of 1936–37. None, however, had spawned more than once before the present season.

Growth.—Fry were first noticed in the small streams at the beginning of May. They were then about 24 mm. long (standard length) and very slender in form. Fish taken from the same waters in October were 45 to 55 mm. in length. Most of the one-year-old fish taken in April and May were 64 to 76 mm. long and weighed from 3.9 to 7 gm. Individuals which have lived in the main river may show much greater growth, and specimens up to 142 mm. and 42 gm. have been taken in April at the end of their first year.

Except during the spawning season, few fish over six inches in length or two years in age are found in these small streams. Larger fish, taken during the spawning run or at other times in adjacent parts of the main river, show much variation in size within the same year classes. Owing to the long spawning season, there is of course considerable difference in size between different individuals of a year class. A rough average weight of 1 pound, 2 pounds, and 3 pounds may be assigned to fish at the end of the third, fourth, and fifth year from the time of hatching. Some individuals considerably exceed these figures.

Food.—A study of the food of the trouts of the Cowichan river system has been made by Mr. C. P. Idyll and the findings will be published in due course. Consequently only a brief statement will be made here.

Chironomid larvae appear to form the most important food supply of the smallest fish (up to two inches in length), with mayfly nymphs second in importance. As the fish increase in size, Trichopterous larvae and adults become the largest invertebrate source of food, while for brown trout of twelve inches and over, fish, consisting of salmonids, sticklebacks, and sculpins, probably equal all other food supplies in importance.

Ecological relations.—There is a general similarity between the food of the brown trout and that of the cutthroat of the same waters. The young cutthroat, moreover, occupy the same streams as the young brown trout, so that a certain amount of competition between these two species seems inevitable.

The dominant species in these nursery waters is the coho, which feeds on the same kinds of bottom organisms as the trout, but also makes efficient use of surface food supplies which the trout utilize to a much smaller degree. In view of their great numerical preponderance, however, the young salmon undoubtedly secure the largest share of both benthic and surface food supplies. In the spring the yearling cutthroat feed heavily on coho fry, but many of the brown trout are still too small to utilize this source of food to any appreciable degree.

The rainbow does not populate the above-mentioned small streams nearly so much as the cutthroat. In the corresponding part of the main river, where this species is more plentiful than the cutthroat, the diet of the larger rainbows appears to contain relatively fewer fish than that of either the cutthroat or the brown trout.

Distribution.—Although brown trout have been planted at several widely separated points in the Cowichan River and Cowichan Lake, little is known concerning the present status of the species except in the part of the river just below the lake, where it is present in limited numbers throughout the year. Fish have been taken in Bear Lake, a small body of water connected with Cowichan Lake, and have been reported from various parts of the main lake and from Duncan, six miles above the river mouth. There is no evidence to indicate that any of the fish have migrated to the sea. In the part of the river system where the brown trout is known to be established the numbers do not appear to have increased within the last year or two.

At present, brown trout form a negligible proportion of the angler's catch, even in the upper part of the Cowichan River. Records obtained from individual anglers in the spring and early summer of 1939 from this part of the river list only 5 brown trout as against 234 rainbow and 58 cutthroat trout.

Little Qualicum River System

Evidence of natural reproduction in the Little Qualicum system is in large part circumstantial. A considerable run of brown trout took place in this river in the early part of January, 1937, and those fish which were examined showed that the gonads were in an advanced condition. In the spring of 1939 a spent fish was taken in the river. A five-inch brown trout was reported to have been captured and released in June, 1939.

The largest brown trout reported from the Little Qualicum was a male weighing 2 pounds 6 ounces in the fall of 1938. Others have weighed between 1 and 2 pounds.

The opinion prevails that the species has declined in numbers since 1937.

Brown trout have been taken in the tidal parts of this river, right to the sea, some of them having a general silvery appearance, with red spots lacking. There is no direct evidence, however, that fish have traveled out to any great distance from the river mouth.

General

Speaking in general terms, it may be said that the brown trout is now established in parts of the Cowichan River and the Little Qualicum River. It reaches a relatively large size in these waters. It is not numerous in either system and does not appear to have increased in numbers within the last year or two. It seems possible that an increasing number of fish will be caught when the product of the natural spawnings of 1937 and 1938 have reached legal size.

The brown trout probably faces considerable competition from the cutthroat and, in the younger stages, from the coho. It is yet early to foresee its ultimate status in relation to the native fish of these waters.

There is some difference of opinion among anglers concerning the merits of the brown trout. In the Cowichan river system it appears to take less food at the surface than the native rainbow trout. It is not numerous enough at present to permit a definite answer to the question of whether it can provide better summer fishing than the native species.

THE EFFECTS OF LOW OXYGEN AND OTHER EXTREME CONDITIONS ON SALMONOID FISH

By Lawrence D. Townsend and Don Earnest*

The occurrence of very low dissolved oxygen concentrations as the result of pollution in the estuary of a river that maintains important populations of salmon and trout has been reported (Townsend, Eriksen, and Earnest, 1938). Although the investigation of the field conditions is still in progress, enough is now known to state that at certain times rather high concentrations of pollutants, particularly waste sulfite liquor, may accumulate in the area where the dissolved oxygen is seriously depleted. It becomes of practical interest to determine the minimum of dissolved oxygen under which the affected species of fish can exist, whether such minimum oxygen values are influenced by the presence of pollutants in appreciable concentrations, and whether exposure simultaneously to nonlethal low dissolved oxygen and the pollutant adversely affects the fish.

The subject of pollution has been considered in relation to fish in many investigations in Europe and the United States, but the salmonoid fishes have not been used as the experimental animals as often as have other kinds. On the Pacific Coast of North America, however, the salmons and trouts are of so great recreational and economic importance that it is desirable to experiment with them in relation to pollution.

This is the more desirable since their anadromous life history necessitates migration through areas of known pollution during the times that conditions have been found to be critically acute. Furthermore, in certain polluted areas, such as Grays Harbor, Washington, the economic fishes found there are almost exclusively Pacific salmons and trout. Our experience has indicated that, under proper conditions, salmon and trout are highly satisfactory laboratory organisms. The wide distribution of certain species such as the rainbow trout in the countries bordering on the Pacific would seem to warrant the substitution of salmonoids for *Fundulus* and other favored species, in much experimental work on fish physiology.

Tolerance of Low Dissolved Oxygen by Fish and its Modification by Waste Sulfite Liquor

A review of reported minimum oxygen tolerances of salmonoid fishes is given in table 1, which shows that such tolerances have been reported to differ by nearly eight times the lowest value observed. Some of the divergent results may be accounted for by species and water differences, but most must be explained by the use of dissimilar techniques by the several investigators. So far as these records are complete, it appears that our previously reported results are the only ones in which pure water was used which had not been heated or exhausted by vacuum, or from which the oxygen had not been removed by the respiration of fish or by bubbling out with nitrogen. One experiment, reported below, indicates that the experimental method employed may alter the results significantly.

Material and methods.—The procedure and apparatus used in minimum oxygen experiments have been described (Townsend *et al.*, 1938). Fresh artesian water, having no dissolved oxygen as it came from the main, was aerated to the desired degree and siphoned into five-gallon bottles, in which fish were tested one at a time. A special apparatus, to be described elsewhere, was used to dilute waste sulfite liquor in experiments using this pollutant. The waste

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* Published with the permission of the Washington State Pollution Commission as a contribution from its Laboratory at Gig Harbor, Washington.

TABLE 1

PUBLISHED MINIMUM OXYGEN TOLERANCES OF SALMONOID FISH

Authority	Species used	Minimum oxygen (p.p.m.)	Remarks
Duncan and Hoppe-Seyler (1893)	Trout	1.13	Temp. 7°5 C.
Paton (1902)	Rainbow trout	3	Water used contained oxygen-depleting substances
Gardner and Leetham (1914)	*Salmo fario*	1.13	Temp. 6°4 C. } Dyspnoea at somewhat higher oxygen
	S. fario	3.43	Temp. 25° C.
Plehn (1924)	Trout	2.14	
Powers and Shipe (1928)	*Oncorhynchus kisutch* (Walbaum)	0.26–1.11	In sea water, pH 7.10
Gutsell (1929)	*Salvelinus fontinalis, Salmo shasta, S. fario*	1.13	Asphyxiated at 2.5 p.p.m., recovered in 2.67 p.p.m.
Creaser (1930)	*Salvelinus fontinalis* (Mitchell)	1.2	Can stand this for short periods
Wiebe, Gayock, Fuller, and Markus (1934)	*Salmo shasta* (Jordan)	.43	Temp. 13°5 C., fish 1.5–2 in. long, pH 7.2–8
Wash. State Dept. Fish. (1938)	*Oncorhynchus nerka* (Walbaum)	2.4	Temp. 21°1 C., adults
	O. tschawytscha (Walbaum)	2.3 –2.7	Temp. 21–23° C., adults
Townsend, Eriksen, and Earnest (1938)	*O. kisutch* (Walbaum)	1.20–1.24	Temp. 12.1–12°7 C., fingerlings in fresh water
	O. kisutch (Walbaum)	1.10–1.14	Temp. 10–11°3 C., fingerlings in sea water
	Salmo clarkii (Richardson)	1.20–1.24	Temp. 10.8–11° C.
	S. gairdnerii (Richardson)	1.50–1.54	Temp. 11.1–13°2 C.

sulfite liquor was received in glass containers from a pulp mill at Shelton, Washington.

The general characteristics of this waste have been described by Benson and Partansky (1934). The principal characteristics are dark brown color, high specific gravity, high acidity (pH 1.8 to 2.1), strong reducing properties, large content of organic compounds, and presence of free sulphur dioxide. As a result of uncontrollable variation in the liquor as sampled, the different shipments varied in concentration as determined by specific gravity. Because of the apparent variation in strength of liquor, a predilution was always made to a specific gravity of 1.005 (approximately one-tenth the strength of liquor withdrawn from a pulp digester at the end of the pulp-cooking process). Such dilutions were prepared in lots of 5 to 10 gallons at a time. After thorough mixing by shaking, the diluted liquor was applied through the continuous dilution apparatus to the stream of water entering the experimental chambers.

In handling waste sulfite liquor it was assumed that different lots of liquor from the same mill would have the same characteristics when diluted to the same specific gravity. It is possible, however, that different lots of liquor may vary in composition independently of the specific gravity, which might account for some of the variability in the tolerances observed.

In each experiment with waste sulfite liquor, two fishes were tested simultaneously in separate vessels with water drawn from the same aeration apparatus. One fish was exposed to the final concentration of waste sulfite liquor and the other was tested in pure water. The prediluted waste sulfite liquor of 1.005 sp. gr. was continuously diluted to 1 : 1000 digester strength (digester strength assumed to be equivalent to 1.05 sp. gr.) immediately before contact with the fish. Unreliability of chemical methods for measuring dissolved oxygen in the presence of this concentration of waste precluded such determinations in the one bottle. In every experiment, however, a number of determinations of the dissolved oxygen content was made on the overflow siphoned from the companion vessel of pure water. Flows were arranged so that water equal to the volume of the experimental vessel would enter in 40 minutes. It was assumed that during such a short interval the well-known high biochemical oxygen demand of waste sulfite liquor would not operate to affect the dissolved oxygen appreciably, when prediluted waste was used. This assumption is borne out by an oxygen demand experiment described below.

The fish tested were young silver salmon one year of age. The fish were obtained from a state fish hatchery and from a small stream (Burley Creek). All had been under laboratory conditions for four months before the present experiments were carried out. During this time their average weight was between 14 and 15 grams. No fish was used more than once in minimum oxygen experiments. Following our former practice, fish were reported dead when they became helpless on the bottom of the experimental vessel. Usually such "dead" fish were revived when returned to well-aerated water. If the fish did not "die" in the course of the experiment, the individual test continued for 24 hours. As the dissolved oxygen sometimes varied over a range of .08–0.10 p.p.m. during such a period, the values reported are the averages determined from seven to ten samples drawn at different times in the course of the tests.

The water temperatures during the experiments varied between 10°.9 and 11°.2 C. The pH of the pure artesian water was consistently 8.0, while that of the final waste sulfite liquor dilution varied between 6.31 and 7.10 for different lots of liquor.

Effect of 1:1000 waste sulfite liquor on minimum oxygen tolerance.—The results of 108 tests are given in detail in table 2*A* and are grouped in table 2*B* to facilitate comparison. It may be seen that the minimum oxygen concentra-

TABLE 2

THE EFFECT OF 1:1000 WASTE SULFITE LIQUOR ON THE MINIMUM OXYGEN TOLERANCE OF SILVER SALMON FINGERLINGS IN FRESH WATER

Dissolved oxygen range	Controls		Sulfite	
	No. died	No. lived	No. died	No. lived
A				
1.25–1.29 p.p.m.	3	0	4	0
1.30–	1	2	1	0
1.35–	1	0	4	0
1.40–	3	1	5	1
1.45–	3	1	6	0
1.50–	1	2	5	0
1.55–	1	5	4	1
1.60–	0	3	1	1
1.65–	0	3	3	2
1.70–	0	5	2	3
1.75–	1	3	3	0
1.80–	1	3	3	2
1.85–	0	2	1	2
1.90–	0	1	1	1
1.95–1.99	0	3	1	2
Total	15	34	44	15
B (data of A combined)				
1.25–1.49	11	4	20	1
1.50–	2	18	15	7
1.75–1.99	2	12	9	7
Total	15	34	44	15

tion tolerated by the fish in the pure-water series of tests is somewhat higher than that previously reported, but that the minimum tolerated by fish in 1:1000 waste sulfite liquor is much higher still. In pure water 50 per cent of the fish that were tested in the range of 1.20 to 1.59 p.p.m. dissolved oxygen lived. In the dilute waste sulfite liquor only 2 fish out of 27 tested in this range survived and it is only in 1.84 p.p.m. or more dissolved oxygen that 50 per cent of the tested fish lived. We may compare the series of fish tested in pure water with the series in dilute waste sulfite liquor by X^2 computed from the formula

$$x^2 = \Sigma \frac{(m' - m)^2}{m}$$

using the values in table 2*B*. The resultant probability (p) value is less than 0.000001, indicating undeniable significance for the differences observed.

An important result of these experiments is the demonstration that normal fish in pure water have a narrow range of oxygen tensions that is critical for determining the minimum that fish can withstand. The variability in the results obtained from experiments in 1:1000 waste sulfite liquor indicates that such a threshold range for the minimum does not occur in the same way in the fish exposed to the pollutant. This variability in the result may have been caused by unknown variations in the waste sulfite liquor from different shipments.

Although time to "death" has not been considered as an element of the experiments, it was always noted that where both the fishes in pure and polluted water failed to survive the test, the fish in pure water outlived the other. Distress signs—gaping and violent opercular movements—interpreted as evidence of dyspnoic respiration were observed in nearly every fish that lived through the test in dilute waste sulfite liquor. Such respiratory difficulties were observed much less frequently in fish in pure water.

The first explanation suggested for the difference in low oxygen tolerance by the two series of fish is that a toxic constituent of the waste sulfite liquor affects the fish's ability to take up oxygen from the water when it is present in such small amounts. This interpretation gains weight when it is recalled that, throughout the range of oxygen tensions tested, a large part of the fish exposed to sulfite liquor succumbed.

Addition of the waste sulfite liquor made the water more acid. The correlation between hydrogen-ion concentration and respiration of aquatic animals has been the subject of study of a number of investigators, most of whom were interested in the pH as related to the carbon dioxide content of the water. Among such investigators there is disagreement concerning the relation between the pH of the water and the ability of fish to utilize oxygen. Powers' (1922) results, indicating that the ability of fishes' blood to take up oxygen was dependent upon the pH of the medium, have been criticized by Pruthi (1927) and Wiebe *et al.* (1934), who found, however, that the pH did affect the minimum oxygen concentration that *Salmo shasta* (Jordan) could tolerate, but the effect was negligible in the range of pH 6.1 to 8.0.

Effect of dilute waste sulfite liquor on the oxygen content of the water.—A possible explanation for the result is that the dissolved oxygen was actually reduced in the dilute waste sulfite liquor by the biochemical oxygen demand of the liquor. Biochemical oxygen demand tests carried out at this laboratory indicate, however, that the one-day oxygen consumption of a 1:1000 dilution of digester liquor at 20° C. is about 4 p.p.m. It seems improbable that a depletion of as much as 0.1 p.p.m. would occur in the first 40 minutes with the temperature at 12° C. Furthermore, it was the usual observation that fish remained quietly on the bottom of the experimental bottle after the first few minutes. As the water or dilute waste sulfite liquor was introduced at the bottom of the bottle, it is probable that the fish made contact mostly with dilutions that were not older than 10 or 20 minutes.

An experiment was performed to determine whether or not the biochemical oxygen demand of a solution of waste sulfite liquor of 1000 p.p.m. digester strength, treated in the usual way, would lower the oxygen concentration below the value found to be the minimum for small silver salmon on pure water. To a liter flask (actual capacity, 1132 ml.) were added 1000 ml. of aerated tap water. A quantity of diluted waste sulfite liquor sufficient to make a 1:1000 dilution was placed in a small vial which was hung in the neck of the flask by a wire loop slipped over a bent glass rod, which in turn was thrust through a hole in the stopper of the flask. In another hole of the stopper was placed a tube connecting to a manometer graduated to 0.1 ml. The assembly was immersed in a water bath the temperature of which was maintained within one-tenth of a degree Centigrade (at 21°.6 C.) throughout the successive steps. The flask was thoroughly shaken (without disturbing the vial of liquor) and brought to pressure equilibrium with a stopcock open. When no further change in volume was observed after 40 minutes with the stopcock closed, the flask was violently shaken so that the wire loop holding up the vial of dilute waste sulfite liquor slipped off the rod and the liquor was mixed with the water in the flask. The flask was shaken intermittently during the next 40 minutes. At the end of this time a change of 0.04 ml. had occurred in the volume of gas in the apparatus, which was within the range of error of the apparatus. No oxygen consumption that would have interfered with the minimum oxygen tolerance of small silver salmon occurred in 40 minutes.

It is concluded, therefore, that one or more constituents of waste sulfite liquor in 1000 p.p.m. digester strength displays a toxicity to fish by interfering with the ability of small silver salmon to utilize dissolved oxygen at the concentrations known to occur in natural water where waste sulfite is discharged.

Effect of re-use of water on the minimum oxygen tolerated.—The differences in the minimum oxygen tolerances for salmonoid fishes that are reported by various workers have been noted. As several investigators reduced the oxygen content of the water by permitting the fish to use up the oxygen, it appeared that the resulting accumulation of carbon dioxide, or other products of metabolism, might have influenced the results. One experiment was carried out to examine this question.

Young silver salmon from the laboratory stock and the same water supply (but now aerated nearly to saturation) were used. Forty fish were placed in a five-gallon bottle into which was running a controlled flow of water having a high dissolved oxygen content. The flow was reduced so that over a period of 2¼ hours the oxygen dropped from 7.75 to 2.88 p.p.m. (as determined by the permanganate modification of the Winkler method) and the free carbon dioxide rose to 6.7 p.p.m. (carbon dioxide content of the supply water was zero). The fish showed no signs of acute distress. The next day the flow was reduced again (after having been at a high flow during the night) so that the oxygen dropped from 7.67 to 1.85 p.p.m. in four hours. Under these conditions the fish first showed distress by partly turning over near the bottom of the vessel 3½ hours from the start of the experiment, when the dissolved oxygen had dropped to 1.90 p.p.m. and the free carbon dioxide had risen to 4.7 p.p.m. Most of the fish were showing signs of distress at the termination of the experiment when the dissolved oxygen was 1.85 p.p.m., although only a few fish were lying helpless on their sides on the bottom. This result indicates that determinations of minimum oxygen tolerance should be made in water that has not been otherwise altered in removing its dissolved oxygen.

CONCLUSIONS

1. Waste sulfite liquor in the concentration of 1:1000 digester strength interferes with the utilization of oxygen at low oxygen tensions by small silver salmon.

2. The minimum oxygen concentration that fish can tolerate is affected by the experimental method used, and methods of research in which water is altered in any other way than by the removal of dissolved oxygen give results that may not be exclusively indicative of oxygen tolerance, but will show the effect of low oxygen in combination with some other factor or factors.

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PRODUCTION IN INLAND WATERS*

By P. R. Needham

The aims of past production studies in both commercial and sport fisheries have largely been directed toward determining that amount of catch or take that could be safely harvested without endangering the future supply. Such work is one of the principal aims of most fish-management studies, and to date little factual knowledge has been produced from inland waters outside a few scattered results in the East and the West.

Before actual methods used in measuring production are discussed, it would perhaps be well to define what is meant by the term production. Without going into needless detail, and yet to use the term in its broadest meaning from a fish-management standpoint, production of a body of water might be defined as those fisheries products utilizable by man. Such a definition may oversimplify the matter. A host of hairs could be split. We say, "the sea produces fish." This is quite clear-cut. But any fisheries biologist well knows that complicated ecological factors govern production of any species. The entire environmental complex of factors, physical, biological, and chemical, all affect the amounts of fish that man can catch. Various types of production could be defined in relation to various limnological or ecological conditions, such as for example the production of inorganic or organic matter, primary foodstuffs, plankton, and fish foods. However, since this paper is specifically concerned with the matter of fish crops, no further elaboration will be given here.

Methods

As noted by Clark (1934), Eschmeyer (1936), Needham (1937), and others, the creel census is the major means used today in determining production in inland waters. This may be high in one year, low in another, depending upon conditions that motivate most human beings, and, of course, may be entirely independent of the actual condition of the angling or numbers of fish present in any given body of water. The fishing may be fine in a particular lake, but if a depression exists, lack of the wherewithal by anglers may prevent harvesting the fish except by such fishermen or others as are unaffected by such economic maladjustments.

Complete annual records of anglers' catches in selected waters will tell exactly what any water produced in terms of pounds or number of fish per unit of water area. In contrast, incomplete records or random samples of catches, while not giving total "creeled" production, nevertheless make possible a study of trends relating to species, sizes, sexes, numbers of fish, and changes in catch per unit of effort or per unit of gear. Study of such records, if kept year after year, will produce data, useful to fisheries administrators, that can be applied toward prevention of depletion in waters from which the records are obtained.

Several other methods have been developed for study of entire standing populations in small lakes or short sections of stream. These are poisoning with gas or chemicals, draining or pumping dry, and dynamiting or using electrical shocking devices. Attempts have been also made to gill-net entire standing populations, but little evidence of complete success has been noted.

Catt (1934), Smith (1935, 1937), Eschmeyer (1937), Thompson and Bennett (1938), and others have reported on poisoning of lakes to remove overabundant undesirable species, such as yellow and white perch, suckers, carp, minnows, or other kinds of fish from trout waters.

Such procedures permit collecting the entire fish populations. From these data total catchable populations can be estimated. Such severe treatment is, of course, limited to small lakes or short, workable reaches of streams and has the disadvantage of ending at one fell swoop all existing ecological relationships. Restocking later initiates a new complex of factors and in terms of productivity may produce little information useful to future management.

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Production of Trout Waters

What are some of the production figures obtained to date, and what do they give us from a management standpoint?

Surber (1936), in work on Big Spring Creek in Virginia, over a four-year period reports the following production in terms of trout caught by anglers per acre of water area: 1933, 29.7 lb.; 1934, 27.7 lb.; 1935, 34.8 lb.; and in 1936, 30.2 lb. The average over the four years was 30.6 lb. annually. One surprising finding of Surber's was that in spite of doubling the stocking rate in the fall of 1935, production the following year remained approximately the same.

Mr. Russell F. Lord, in a personal communication to the writer, reports that the Furnace Brook Test Stream in Vermont showed an annual catch of roughly 34 lb. per acre.

That famous producer of trout, Fish Lake in Utah, as reported by Hazzard (1935), gave a calculated production of 38.3 lb. per acre caught by anglers.

Angora Lake, a small, five-acre lake lying at 7800 ft. elevation in the high Sierra in California, gave a production of 15.8 lb. per acre in 1934, 21.2 lb. in 1935, and 16.75 lb. in 1936. (Unpublished work by the writer.)

Catch records taken on Fish Lake in the Umpqua National Forest in Oregon as reported by Needham and E. P. Cliff (1938) gave a calculated production of 20 lb., or 66 fish, per acre.

Eschmeyer (1937) in studies of three small Michigan lakes obtained production figures varying between a minimum of 4.3 lb. to a maximum of 30.2 lb. per acre.

Mottley (1939) indicates from a study of Paul Lake, near Kamloops, British Columbia, that approximately 10 lb. of trout per acre are taken from this 1000-acre lake annually.

The above-cited figures for both trout streams and lakes refer, of course, only to production in terms of trout caught by anglers. In contrast with these figures are those obtained by Hoover and G. W. Morrill, Jr. (1939), from two New Hampshire streams where poison was used to destroy entire populations for study.

The two brooks studied had been closed to all angling since 1918, so their study covered primitive conditions—waters unaffected by the factor of angling. No trout had been stocked in either stream since 1928. Both streams rise in the northern end of the White Mountains of New Hampshire. They are of rapid gradient, cold year-round temperature, and poor food supplies. The average poundage of native eastern brook trout was 35.67 lb. per acre. Sculpins were the only other native fish present, and, with the trout, gave a calculated standing population of 41.4 lb. per acre. It is of interest to note that only about 15 lb. of the total 35.67 lb. of trout per acre consisted of fish over a legal length of six inches. Since the study covered only 3.7 miles of stream and since only about 4 lb. of legal-sized fish were available per mile of stream, it is evident that but little sport would be provided.

I have referred only to trout or cold waters. Many figures based on anglers' catches, and poisoning, draining, and other methods noted, are available from warm waters inhabited by such species as bass, pike, perch, bullheads, crappie, and others. Production figures ranging up to more than 1143 pounds per acre

(Thompson, 1939) have been obtained, with many running from 200 to 400 pounds per acre. Such figures include all fish, of both game and nongame varieties. It is quite evident from the little work done to date that warm waters are much more productive than the colder waters. We might even say that the upper limit of production in trout waters generally, including both streams and lakes, is around 40 lb. per acre.

There is good reason to believe that many trout streams, because of low year-round temperatures and poor food conditions, like those studied by Hoover and Morrill cited above, cannot be expected to produce over 10 or 15 lb. per acre of water area.

These figures indicate a few of the scattered production findings that are slowly seeping into print. They are concerned, for the most part, with anglers' catches.

What about potential production? From a management aspect, actual production should parallel or closely approach potential production. Use of the term "potential production" implies the possible use of fertilizers, fish shelters, predator control, planting of new species, fish foods or plants, spawning bed improvements, and so on, to increase production. The highest possible production consistent with all economic benefits of our waters is, of course, the ultimate aim.

Application of Production Data

The question, What do production figures give us from a management standpoint? remains to be answered. From a research point of view complete catch records from carefully selected test lakes and streams will, over a period of years, produce basic facts that will form the foundation upon which actual management measures may rest for waters on which the records were taken, and for bodies of water similar in kind.

But there is more than fact finding in this fisheries game. Management as such entails administration. Administration of fish and game by usual legislative processes is cumbersome, inadequate, slow, and often too largely political. The laboratory, be it indoors or out, is a long way from where the fish and game committee sits in session, but the distance is greater in thought than in miles.

The point emphasized here is that management must depend upon facts produced by research. Management is the cart, research the horse. We hear much loose use of the term "management," but we have yet to hear of the complete and efficient management of a single open, public, inland body of water outside of fish cultural establishments.

Complete catch records cost money. And it is not going to be within the realm of possibility to obtain complete seasonal records except as funds, time, and personnel permit in a few carefully selected test lakes and streams. Random samples can be obtained easily and cheaply, but before such records can be applied they must be taken over a period of several years before trends, as such, become evident. It is my earnest belief that much sounder and more useful management data will come from complete records than from random samples. Much parallel experimental work can be carried on at the same time on such matters as survival of planted trout, contribution of naturally propagated trout, experimental improvement work, and population studies in relation to food supplies. Anglers' records should be backed by suitable legislation because experience has proved that voluntary random returns are quite inaccurate and incomplete. Concentration of work on test lakes and streams will therefore give more data and better control.

Unfortunately there are those who would have us, like Aladdin, rub the "scientific lamp" and thus quickly solve baffling problems that have confronted fisheries investigators for years. We are fortunate in having accumulated a large body of basic facts in fishery science, but we have been sidetracked into developing techniques. They have got to come first and they are on the way. Meanwhile those who hold the purse strings figuratively writhe in agony waiting for results.

This little matter of funds for inland game-research studies recalls a statement made by Schultz (1936). He says, "Probably if the same attention had been given to the game fisheries as it was in the sea fisheries of the North Sea and elsewhere and as much money made available as for even one of the large marine investigations, we would have our freshwater game fisheries under scientific management today." Game fisheries investigations are, and always have been, the financial orphan in conservation work.

What do we have in the way of actual management? Fish hatcheries for restocking spent waters. True, but we do not know how much good they are doing us. Millions of fish are planted, millions are caught; but where did they originate, from a natural redd or a hatchery trough? The planting of marked hatchery trout coupled with records of anglers' catches are slowly but surely telling us the cost in terms of money and survival.

In addition, we have stream improvement or, as one school of thought puts it, "environmental control." There is no doubt that stream improvement will achieve a definite and useful place in management programs, but to date, outside of work by Tarzwell (1936, 1938), no attempt to evaluate results in relation to its cost has appeared. I might add, too, this is going to be a hard task.

The closing of small feeder, breeder, or nursery streams has long been a happy practice of conservation-minded legislators. The only study made to date to find out the true value of such closures in eastern brook trout water has been done by Hoover and Morrill (1939), in the paper cited earlier here. They say: "There are no indications that the closing of feeder streams, or as some say 'breeder streams,' is of any benefit to the streams to which they are tributaries. The contention that brook trout will drop progressively down stream as they increase in size, seems fallacious. Closing feeder streams will result only in the reduction of miles of available fishing waters, and will not benefit the main stream." And they submit evidence in support of their statements.

The fact that closures of small, cold eastern brook trout waters have not given the desired results is not, by any means, sufficient reason for assuming that such closures may not benefit other types of streams containing the same or other species of fish. Closure of certain tributaries of streams containing steelhead trout may be of great value in protecting these fish following inland migrations. Such closures may also be useful in assuring larger escapements of the young produced.

Closure of small tributaries of lakes to protect spawning runs of lake-dwelling trout in the high Sierra in California has produced apparently good results. But here, too, we have only general observations and no quantitative evidence whatsoever of the usefulness of this type of protection in high Sierra lakes.

Most common management measures in use today are quite similar in kind to that just cited. Bag, size, and seasonal limits fall in the same category, and some progress has already been made by application of investigative findings to make such legal restrictive measures in accord with the life histories of the game they are intended to protect.

What about planting of trout? Not much improvement can be noted on the whole, and as a subject for research it offers many baffling problems that will take much time to solve. Improved methods relating to the best times, places, and manner of actually placing fish in waters remain to be developed. Mechanical aids for transporting fish to the waterside have been improved, but biological data on planting methods lags behind.

In connection with planting of trout it would be well to point out that the fact that fish are well adapted and do well in hatcheries is not proof, by any means, that they are equally well adapted to wild waters. A careful study of the hereditary background of hatchery brood stocks, especially with regard to migratory habits and temperature tolerances, would make it possible to plant the offspring of hatchery fish in waters where their best possible utilization and survival to anglers would be assured. Selective breeding of trout has already greatly increased the possibilities of hatchery production. But will such fish when planted in streams increase anglers' production? Steelhead have been crossed with the so-called Shasta rainbow of early-day fish culturists; cutthroat have been crossed with rainbow and steelhead; rainbows with golden, and so on, until today it is pretty much anybody's guess what the genetic constitution of most hatchery-reared brood stocks may be. They might well be termed fish-cultural alley cats. Genetics of game fishes is a relatively unplowed field. A detailed knowledge of the life history and habits of our game species will yield just as great returns in applicable facts for the use of fish managers as agricultural research has produced for farmers. A really effective program of management can be had only if, first, the necessary facts are obtained and, second, these facts are applied in behalf of the fisheries concerned.

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BOAT-CATCH STUDIES AS AN AID TO INLAND FISH MANAGEMENT

By H. B. Nidever and Richard S. Croker

The goal of every fisheries administrator is a fishery that will give the fisherman a maximum return for his fishing effort. In order to attain this ideal the administrator must first learn everything possible about the fishery—the life history, habits, range, and abundance of the fish, as well as fishing methods. Then come analyses of his facts and their application in the form of regulations, stocking, or whatever else may prove necessary.

In the past, the research man has placed more emphasis on life-history studies than on arriving at an understanding of the abundance of the fish in question. Consequently, laws were enacted and artificial propagation was carried on without proper knowledge of their necessity or their result. Both methods for improving fishing were based on a sound foundation as far as habits and life history are concerned, and it is doubtful that fishing would be as good as it is in our streams and lakes if these lines had not been followed. However, with more and more people turning to fishing as a recreation, the demands upon the administrator are increasing, and in order to satisfy the fishermen whom he serves he must seek every bit of information that will enable him to improve fishing.

Without a knowledge of the relative size of the fish population and of changes in abundance or availability, it is not possible to maintain good fishing in the face of present-day intensity of effort. The wise administrator has awakened to that fact and is attempting to learn something about the abundance of fish in his waters so he can manage the fisheries in a businesslike manner. The shopkeeper with his inventories knows how much stock he has on hand, how much he has sold, and how much he will need in the way of replacements. The cattleman knows how many head of cattle he has, how many calves he can expect, how many head the range can carry, and can estimate how many he can sell without reducing his breeding herd. The fisheries man cannot count his fish, he cannot count the eggs and larvae, nor can he depend on environmental factors to be always the same (Scofield, 1939). He must depend on catch statistics to tell him what he needs to know. To be sure, he can count the salmon on the spawning beds, the young clams on the beach, the oyster spat on the receivers—but nine times out of ten he must obtain his information the hard way, by getting records of the fishermen's catch.

By this I do not mean that we should drop all other lines of research and concentrate on catch studies. Far from it. There is still much to be learned about the life histories of our fish. Stream and lake surveys are necessary to ascertain how many and what kinds of fish our waters can carry. Catch studies are merely supplemental; they tell us how many fish are removed from our waters, and indirectly they tell us how many are left—but principally they tell us whether or not enough are left to reproduce and maintain good fishing.

Let us picture for a moment the ideal condition, which is seldom to be found. On a given body of water we have installed a system for obtaining complete catch records. Every fisherman, at the end of his day's fishing, reports the number and size of the fish he caught and how long it took to catch them. Before long we have a good idea of the return per unit of fishing effort, that is, how many fish per hour of fishing, on the average, or how many hours per fish, for that matter. If there were fewer fish per hour the next year and even fewer the following season, it would be obvious that something should be done to improve matters. In the meantime we would also have been obtaining notes on size and condition of the fish caught, water temperatures, food supply, spawning facilities, and so on. Correlating these facts along with a diminishing yield, it would be fairly simple to know what steps to take.

However, the time has not yet come for obtaining records of this sort on a large scale. It can be done and is being done on various test streams and lakes here and there, and these experiments are pointing the way toward better fish-management practices. For larger fisheries we must still rely on incomplete catch records—which are far better than none.

As an example of an effort to place a fishery on a management basis, let us consider the striped bass fishery of central California. About sixty years ago the striped bass (*roccus lineatus*) was introduced to California from the Atlantic Coast. This fish has taken naturally to our waters and has become one of our most valuable fish. Within a few years of its introduction there was a thriving commercial bass fishery throughout its range, which includes all the lower reaches of the Sacramento and San Joaquin rivers and their delta as well as San Francisco Bay and near-by parts of the Pacific Ocean. Sport fishermen were slow to go after these fine game fish, and not until ten or fifteen years ago did the sport fishery really have its awakening. Now thousands of people from the valley and bay cities are enthusiastic bass fishermen. In fact, the anglers became so numerous and enthusiastic that they were able to remove the bass from the market, and since 1935 this fish has been purely a hook and line sportsman's fish. Fishing has become so intense that there are grave doubts that the bass can stand up under the strain. We have a working knowledge of the habits and life history of this fish as a result of scientific studies pursued by the California Division of Fish and Game (Scofield, 1931). All we needed was a measure of changes in abundance. It was fairly easy to obtain this measure when the bass was a commercial fish, as the Division has had complete records of market landings since 1915. These records, as far as striped bass were concerned, showed that there was no lessening in the supply. The annual catches of about a million pounds were not endangering the bass, as an analysis of boat catches showed (Clark, 1933; Craig, 1930). But that was before tens of thousands of anglers lined the banks and blocked navigation with their boats every week-end in pursuit of bass. With no commercial catches to measure and no provision for measuring anglers' catches, it was incumbent upon the Division of Fish and Game to take steps that would enable it to determine changes in availability. If it didn't and the fish were wiped out, the bass anglers would have just grounds for complaint.

Consequently, the authors made a preliminary survey in 1936 and outlined a program which really got its start a year later and which has improved gradually since then. At the outset the idea of getting the catch of the individual fisherman, which had been given due consideration, was abandoned as it was deemed impractical, at least for the time being, to attempt to get the desired information in that way. The area involved is too great—many hundred miles of river and bay—and there are too many fishermen. Getting the individual reports would be an ideal arrangement, as we would then know the exact number of people fishing and exactly when, where, and how they caught their fish. However, under present circumstances, this is practically impossible—although it will be done some day. There is no good reason why every person fishing should not report his catch if proper facilities were provided by the State to make it convenient for him to do so. In the meantime we will have to make the best of what we are able to get and continue to pave the way for something better.

A great deal of the fishing is carried on from rented skiffs and chartered boats. In the bass-fishing area there are about 45 skiff resorts, with an average of 20 skiffs to the resort, and over 130 charter or party boats. These operate in all parts of the area and at all times of the year. The skiffs are mostly in the delta and river country and the launches principally in the bay, but there is considerable overlapping. The obvious thing to do was to obtain records from the boat operators. By getting them to make reports, we could have a record of the operations of thousands of fishermen and we would have fewer than 200 men with whom to make contact. We could not get the total catch, as many bass are taken by people fishing from private yachts, skiffs, bank, and pier. However, we could get an adequate sample of the catch throughout the year at all points—a measure of fishing intensity and of fluctuations in abundance from year to year, not only in the whole area, but also in each locality.

In 1936 and early 1937 we got in touch with most of the launch and skiff operators and asked their coöperation in a catch-record program. Record books were given to them after explaining the situation. The response was fairly good. The more observant and businesslike ones were already keeping records and were glad to coöperate. Others refused point blank. Many started with good intentions but became negligent and forgetful. All in all, we obtained some fine records, but it became apparent that voluntary coöperation was not enough. A law requiring the keeping of records was necessary, just as we had found in our ocean fishing program. The law was passed in 1937, and since then there has been less difficulty in collecting records, although the boatmen are handled carefully rather than threatened with arrest. Incidentally, all reports are confidential and no individual's operations are divulged. We feel that we are getting adequate records now and that the boat operators have come to the point where they take their logbooks or fishermen's registers as a matter of course. It is up to us now to analyze their reports and make the most of them.

It must be realized that catch records have to be taken over a number of years to be of real value in drawing conclusions concerning the actual abundance of a species. That is their principal drawback. In the meantime, the catch records can give us much worthwhile information. As for the striped bass records, they indicate how many other kinds of fish are taken by bass anglers—salmon, black bass, flounders, catfish, and even an occasional shad. They will also indicate what conditions influence the movements and apparent short-time changes in abundance—hot or cold weather, water temperature, salinity, and the amount of mud or silt present in the water. A better understanding of these things will lead to improved fishing.

In conclusion we would like to repeat that to administer a fishery properly we must have accurate knowledge of relative abundance and that such knowledge must usually be derived from the collection and analysis of catch records. When complete catch records are not possible, samples will suffice, and often these samples can best be obtained from the operators of skiff resorts and charter boats.

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THE INVESTIGATION OF THE FISHERY RESOURCES OF THE AUSTRALIAN COMMONWEALTH

By Harold Thompson

It is of course impossible for one organization with limited personnel and with one small research vessel to survey as a whole, and at one and the same time, the fishery resources of a continent with 12,000 miles of coast line. It must also be remembered that marine investigations have to extend seaward and down to considerable depths, so that the task in Australia is colossal. The first approach toward a workable plan is to subdivide the area in as natural a fashion as possible, and to concentrate to begin with on the most accessible and promising portion.

Our first subdivision is a natural and obvious one—that into tropical and subtropical areas. Of these two we have little hesitation in selecting for prior study the cooler subtropical area, and to prefer the east to the west side of the continent, since it extends into more southerly latitudes and therefore into coolest waters, where it is the normal thing to find the best commercial fishery prospects. Part of the south coast must also be included. This is so since, although most fish species make their seasonal migrations in a north–south or south–north direction in order to have a choice of temperature conditions, we must expect that some of the eastern species will, at certain periods of the year, overflow a certain distance westward along the south coast. Actually the area which has been selected for more intensive initial study extends from around the Tropic of Capricorn to Tasmania and South Australia. This zone covers approximately one-quarter of the whole coast line of Australia, and concerns five of the states. It is also the most populous sector, where communications and general working facilities are best developed. At its center there is an established fishing industry based on Sydney. From all accounts this area has in its waters certain fish species worthy of investigation, and any subsequent commercial developments should here have the best opportunity of making rapid progress. I will show later why it is necessary to spend some considerable time in assessing the possibilities of one sector at a time. When definite findings have been reached in the southeastern sector, these findings ought to find their application in the southwestern area in similar latitudes, which should therefore be capable of a much more rapid survey later on.

The Commonwealth investigations are planned, in the first instance, to evaluate the prospects of basing a fishery on the pelagic fishes, that is, the fishes which live at or near the surface. Among such fishes, from which a very large income is derived in other countries, but from which little income is derived in Australia, are the pilchards or sardines, and the several species of large mackerel-like fish which are called tuna. Some of these species occur in the southeastern area, and one need is to discover just how reliable their occurrence is. From the commercial fisheries standpoint it is of paramount importance that runs of fish should extend over a good many months. In increasing extent, as time goes on, preliminary surveys are expected to be made in the southwestern area, as well as in the tropical area, where there occurs one tuna species in particular—the yellowfin tuna, which is all-important in the Californian industry, and which must therefore receive a measure of study early in the investigations. Thus, whilst the research vessel is concentrating on working the southeastern area, it is hoped by reconnaissance by aircraft and possibly by small chartered vessels to obtain preliminary information in a much wider area.

By confining the more intensive investigations to the southeast area, and within this area to pelagic fish, the task is reduced to somewhat manageable proportions. The other class of fish—ground fish or so-called demersal fish—were investigated in the earlier years of the century by the steam trawler *Endeavour,* with the result that the Sydney trawling industry has evolved. There is reason to believe that no great extensions of this industry are likely, since the suitable area of the continental shelf in the colder zone is strictly limited. It was originally thought that 120 trawlers could be continuously supplied with fish from this area, but in the actual event fewer than 20 have been in continuous operation. On the other hand, the possible scope of the pelagic fishery is, theoretically at least, very great. This would appear to be so since such fish are not, like the ground fish, confined in their movements to the very restricted continental shelf, but can adopt a larger part of the ocean for their habitat. Moreover, their food supply can be continuously renewed by nutritive organisms swept in from the great oceanic area by suitable currents. At all events, the possibilities of the pelagic fisheries should be evaluated and the whole subject removed from the realm of conjecture.

Having thus selected for first study a natural unit of the entire area, and, within that unit, chiefly the fishes in the upper water layers, what methods of survey are to be adopted? Obviously, to obtain a broad conspectus of the seasonal and periodic distribution of the fish shoals, the area must be traversed as frequently as possible. Fortunately, through the foresight and vigor of Mr. S. Fowler, an officer of the Fisheries Section of the Council for Scientific and Industrial Research, it has been amply demonstrated that under favorable conditions rapid and profitable surveys can be made from the air. With the generous coöperation of the Air Force, such surveys may yet become a routine part of the survey program. Several reasons could be advanced to explain why aerial reconnaissance of upper-water fish shoals has proved successful in Australian waters, whereas elsewhere this method of survey has met with indifferent success. Of these the high-angle incidence of the light rays, the absence of silt in the water, and the bright background so often provided by sandy bottom seem most plausible. To sum up briefly the outcome to date of this aerial work, which has been proceeding for more than two years, it can be said that the general distribution of certain of the more prolific pelagic fishes—for example, tunnies, salmon, pilchards, and related species—have been distinguished in a general way from the air, and valuable guidance, at least in the preliminary stages, given to the movements of the research vessel, which has by her catches confirmed the aerial evidence. Naturally the vessel will at times catch, for instance, tunny which rise to the lure from deeper-water layers where they were unobserved from the air, and to this extent the agreement is imperfect. The fact remains that the broad distribution can often be indicated, and this is of very great value in the early stages. Much fruitless cruising of the vessel can be and has been avoided. The formation and extent of the shoals is also most clearly seen from the air. For example, more than 100 shoals of tuna were recently observed together, off Bermagui, the area covered by them being 10 miles in extent. As a result of combined work by aeroplane and vessel we are rapidly becoming acquainted with the exact seasonal distribution of tuna in the southeastern region. Showing up against the sand in shallow water, salmon (*Arripis tritta*) give even clearer results.

The more specific and detailed work has, however, to be done by the research vessel. This vessel must traverse the entire area of study as frequently as possible, so that precise limits of distribution, together with seasonal movements, can be defined beyond doubt. Occasionally the vessel must linger in an area within which fish are more densely assembled in order to try out various methods of fishing. The ultimate object must of course be to establish the limits of the catches which could be made in a unit of time by vessels fishing on a commercial basis. Once the distribution of the fish shoals has been determined, therefore, it becomes necessary for the research vessel to operate on a quantitative basis, using different types of fishing gear.

For how long must such work proceed within the specified area? It is not at all sufficient to say that, because large shoals of a certain fish species have been located in an area, a fishery ought to, or could be, established there. We must be well on guard. Variations occur in the systems of sea currents from year to year, or in irregular cycles of years, and very often these variations affect the movements and positioning of fish shoals. The fish may lie farther to the north or south, nearer inshore or farther offshore, or shallower or deeper than usual. To take a recent concrete example, the Canadian pilchard fishermen were last year worried on account of the failure of the pilchards, for the third time in six years, to arrive off their coast. Explanation or anticipation of this failure was lacking on account of insufficient scientific data. Another necessity is to determine whether there are large fluctuations in fish numbers from year to year. Some species fluctuate more than others. During ten years' study of the haddock of the North Sea, the writer found the net product of one spawning season to be up to sixty times as great as that of another, with all variations in between these extremes. This meant that there were, from time to time, quite different amounts of young haddock coming on to affect the commercial catches, which fluctuated as much as 50 per cent either way in consequence. From three to five years' study should, however, suffice to indicate what short-term range of fluctuation could be expected in Australian waters. Another variant to be cognizant of is the average size of the fish. This varies partly according to the variation in the average age of the fish in the shoals. Food supply is another factor affecting the size and, of course, the condition of fish. Growth in one area may be much more rapid and maturity more rapidly obtained than in another area. There are of course best fishery prospects in the areas of rapid growth. Thus haddock of Iceland grow more rapidly than haddock of the Grand Bank of Newfoundland, and these in turn grow very much more rapidly than those of the North Sea. Naturally the Iceland area has proved the most consistent source of this fish. Even on different parts of the same coast there can occur variations in growth rate—for example, the cod in the colder waters off the Labrador coast, with a short feeding season, grow very much more slowly than the cod off the warmer New England coast. Already we have indications that the same thing can occur in Australian waters. Obviously a fast-growing race of fish will sustain a more intense fishery than will a slow-growing race. Replacement of loss due to the fishery will be more rapid. In summing up the long-range prospects of a fishery, all these factors should be taken into account. We can put it this way: if a certain species, of good quality, can be shown to occur in great numbers with a good average size and growth rate, and if this species is present with a high measure of reliability over a period of several years, there is little danger in stating that a reliable and enduring fishery can be based upon it—that is, if it is also shown that it can be caught with a fair measure of ease, and if safe harbors exist near by. Even so, as we have learned by experience elsewhere, research work should go on for a prolonged period alongside the developing fishery, if we are to understand and anticipate the variations bound to occur. There are few fisheries today which do not call for and receive continuous scientific study of cause and effect. A further complication is introduced when to natural variations is added the impact of man's efforts at exploitation, often carried out without a thought to the future. Most fish stocks today are suffering from overfishing—that is, the removal of a greater weight of fish than can be naturally reproduced. Only too often, also, the removal takes place of a disproportionately large number of young, immature fish which are of little or no commercial value but which it is all-essential should be left in the sea to rehabilitate the general stocks. There is of course no need to delay the commencement of a fishery until a complete knowledge of all the vital factors is obtained, since any new fishery will naturally begin on a modest scale and develop step by step. But there is immense significance in obtaining a sound preliminary knowledge of a fish stock while it is a virgin stock, unaffected by the onslaught of a commercial fishery. It should be the ideal to endeavor to maintain the stock as nearly as possible at its original strength of numbers, and without decrease in the average size of the individual fish. It is the function of science to determine the maximum yield which can be derived without seriously depleting the resources. It is also its function, when depletion inadvertently occurs, to show how the stocks can be nursed back to proportions somewhat commensurate with those originally existing, and to maintain them at or about that high level.

Assuming a new fishery can be started—say, on tuna or pilchards in Australian waters—what are the various courses that fishery can follow? Consider the course of events in the California fisheries for these species. From small beginnings twenty-odd years ago the tuna fishery has steadily increased until 70,000 tons are being landed annually. And the production curve is still rising steeply. Here we have an example of a fishery whose maximum limit of production has still to be discovered, though it is unlikely that the stocks will long sustain production at that level. Depletion is likely to set in, as it has in the enormous pilchard fishery. This fishery is doomed to decline still further unless corrective measures are taken, as they have been taken with respect to the Pacific halibut. These measures, based on thorough biological and statistical evidence, are, with the utmost precision, gradually elevating the halibut stocks to higher recovery levels. As each recovery stage is consolidated a further measured increase is allowed in the permissible catches. The halibut fishery is thus well on the way to becoming a gilt-edged proposition. Some few fisheries, like the Norwegian cod fishery at Lofoten, show a quite different course, since they have never been overexploited. They proceed for centuries at or around the same conservative level of intensity, fluctuations being due to natural causes and market requirements. Most fisheries, however, are of the first type, showing a sharp rise to a maximum which cannot be sustained, and thereafter just as sharp a decline, which must be checked if virtual extinction of the fishery is not to be faced. Classical instances are those of the plaice—the chief flat fish—and of the haddock—the chief round fish—of the North Sea. Take for example the catches of the larger sizes of haddock in recent years. Long before the war, and for a very brief period after the closed season imposed by war conditions, it was customary to secure a sizable haddock on almost every hook attached to a long line lowered to the sea floor. When the writer left off the study of the North Sea haddock stocks in 1930, the decline in numbers was startlingly evident, but further sharp decline has since proceeded until the point has been reached where no one expects to catch a large haddock in the North Sea. It has become necessary to go to Iceland or the White Sea to obtain large haddock. But this move to more distant grounds is only a temporary remedy and a palliative. For example, Hjort[1] has shown that for the Norwegian prawn fishing new grounds are limited, and will only stand up for a short time to a wasteful form of fishery. He has shown experimentally how by enlarging the mesh of net used and allowing unmarketable small prawns to escape the fishery could endure on a rational basis. The far-off haddock grounds will go at least a good part of the same way as those of the North Sea, and then, and apparently only then, with no new fields to exploit, will really conservative measures, on the lines followed for halibut, be taken. The alternative is uneconomical prosecution of the fishery, in an atmosphere of complete doubt concerning what the future will bring forth; the ultimate descent to an annual yield far below the maximum which could safely be secured; and, as with respect to the whale fishery off the Spanish coast, the ultimate fall in the curve of production to a level at which it no longer pays to fish. It is obviously opportune to be wise before, rather than after, the event. Many may think that it must be a long time before there is any likelihood of depletion of Australian fish stocks, since the fishery industry is as yet a small one. We have learned, however, that a period of a very few years—indeed, eighteen months where haddock are concerned—can be sufficient to make serious inroads on available supplies, and the case for early and continuous biological and statistical study is quite clear. For North Sea haddock the facts are so well known through continuous study that the scientist can and does accurately forecast the course of the fishery for eighteen months ahead. This forecasting service can tell how the average catch will rise or fall, what the average length of fish will be, and in what areas best catches will occur.

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[1] Johan Hjort. Human Value of Biology (Cambridge, Mass., Harvard Univ. Press), 1938.

In approaching the preparation of a plan for effective research into Australian fishery possibilities, these considerations are of paramount importance. We must be out to obtain real and fundamental knowledge which alone can furnish facts and dissipate doubts. The ultimate object is to be able to say what average annual yield can safely be taken from a fish stock without detriment to that stock, and to anticipate such fluctuations—due to natural causes—as will inevitably occur from period to period.

We must therefore make adequate provision for the following subsidiary studies, to proceed alongside more exploratory work. Hydrological work is essential, including the continuous study of the variation in the physical conditions at sea, and the study of the fluctuations in the chief current systems; for the determination of the optimum and the limiting conditions for each species separately, part of this study to be carried out under controlled conditions in the aquarium. A certain amount of investigation will also be necessary into the fundamental productive capacity of Australian waters as indicated from their content of nutritive salts, such as phosphates, nitrates, etc. If the amounts of such nutritive salts are consistently low in Australian waters, then the outlook for a very large and sustained fishery would not be very bright, although it must be remembered that pelagic fish might easily compensate for a low general level of food supply by foraging over a vast area. Also, that incoming currents could continually renew the supply. In addition to these hydrological studies, biological studies must be made, mainly of the chief pelagic fishes, including the determination of their spawning grounds and seasons, their migrations, their average ages and rates of growth, their feeding habits, their age on reaching maturity, and the chemical analysis of their flesh so as to determine, particularly from the oil content and the seasonal changes in the ratio of water to fat, their suitability for different forms of processing for the market.

These are the essential lines of work to enable well-founded conclusions to be drawn concerning the probable limits of extension of the Australian pelagic fisheries, which latter are the more immediate object of study. In conclusion it may be mentioned that it is not proposed to confine the work entirely to pelagic fishes. There are important inshore species, such as mullet and Australian salmon, and of course shellfish, notably oysters, deserving of study of a kindred nature. Finally, there has to be considered the whole question of the best methods of fish preservation and transport. Preliminary bacteriological investigations have been commenced on this subject. Provision is also being made to conduct freezing, canning, and smoking experiments. It will be seen that the program is a comprehensive one—as a national fishery research program should be.

PHILIPPINE FISHERIES AND PROBLEMS OF THEIR CONSERVATION

By Deogracias V. Villadolid

Introduction

The Philippines, which is composed of more than 7000 islands, large and small, lies southeast of the continent of Asia, almost directly south of the Japanese Empire, and north of Borneo and Celebes, between 116° 40′ and 126° 34′ east longitude and 4° 20′ and 21° 10′ north latitude. The Archipelago is north of the East Indian countries and is entirely within the tropics. It has a coast line of 11,444 miles[1] with about 705,000 square statute miles of territorial waters. This water area is nearly six and one-half times the total land area of 115,026 square miles (297,906 square kilometers). The marine waters include vast areas of bays, gulfs, shallow reefs, and open seas of varying depths. Thus all types of shores may be encountered, offering suitable bases for various kinds of fishing operations.

Theoretically the Philippines not only has extensive fishing banks in its coastal waters but also potential fishing areas in the deep waters of its open seas. We have reason to believe that large quantities of pelagic fishes, which are of great economic significance to the Filipino nation and to her neighbors, are present in our offshore fishing grounds. Japan has already been attracted to the exploitation of the Philippine species of Thunnidae, especially the skipjack, *Katsuwonus pelamis*. This fish is now being canned by a Filipino-Japanese company, the "Sea Foods Corporation," engaged in tuna fishing in the waters of Mindanao and the Sulu Archipelago.

History of Fishing in the Philippines

History has it that the Philippine aborigines, who were nomadic peoples living in the mountains and forests, confined their fishing activities to the catching of fresh-water species of fish and crustaceans by very crude and primitive methods, such as the use of bare hands, by barricading portions of streams with river stones and gravels, and not infrequently by the use of their fighting weapons, the bow and arrow. Shooting *Dalag* or *haruan, Ophicephalus striatus* Bloch, with these weapons, provided them with fish food and recreation. These early inhabitants also used the very destructive method of fishing with fish poisons, which are used up to the present by the natives. In a large measure the depletion of river fisheries, especially that of the mountain streams, can be traced to this ruthless method of fishing.

Later wanderers from the Malay Peninsula reached the Philippines and settled in the coastal regions. It was natural for these immigrants to settle in places where they were assured of sufficient food. Since fish and other aquatic products were most readily available, the first settlements of the Malay immigrants were established on the seacoasts. The settlers brought with them more effective methods of fishing, involving the use of traps in rivers, lakes, bayous, and other shallow waters. The most important of these traps is the fish corral, or *baklad,* of which there are now various styles and sizes. Unfortunately these traps catch the young and the spawning fishes, especially those that have migratory habits, traveling back and forth between the sea and the rivers and lakes. *Baklad* are still extensively used in Philippine waters.

Later the Indo-Pacific peoples, such as the Hawaiians, Formosans, Javanese, and Chinese, reached the Philippines, bringing with them improvements in methods of catching fish, involving the use of seines, gill nets, and long lines or trawl lines. These nets and traps, unfortunately, are almost invariably adapted to the catching of young and immature fishes in shallow waters. The Indo-Pacific peoples also introduced methods of pond culture of the bañgos, *Chanos chanos* Forskål, which now are so highly developed that today the best developed fishponds are probably confined to the Philippines. The fishpond industry requires the catching of large quantities of fish fry of the desired species for the stocking of fishponds.

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[1] 11,444 miles = 18,417 kilometers; 705,000 square statute miles = 1,841,879 square kilometers.

During the Spanish régime our fishing industry did not receive much attention, but with the advent of the American administration interest in the improvement and development of this industry took concrete form.

As early as 1907 the Bureau of Science, in consultation with Dr. Hugh M. Smith and other fishery experts, who had come here on board the S. S. "Albatross" of the United States Bureau of Fisheries on an exploration expedition to study the marine fauna of the Philippine waters, promulgated the first concrete government policy relative to the development of our aquatic resources. In 1921 the Division of Fisheries was created in the Bureau of Science to lend further encouragement to our fisheries work. In 1926 Act No. 3307 was enacted by the Philippine Legislature for the purpose of strengthening this Division of Fisheries. In 1932 Act No. 4003, a compilation of all laws on aquatic resources, known as the Fisheries Act, was passed by the Philippine Legislature. A sum not exceeding 100,000 pesos accruing from the money collected under this Act is set aside yearly for the promotion of the fishing industry. In 1933 the Fish and Game Administration was organized as an independent Division of the Department of Agriculture and Commerce. That Division took over the work of the former Division of Forest Fauna and Grazing of the Bureau of Forestry and that of the Divisions of Fisheries and Zoölogy of the Bureau of Science. The new Division of Fish and Game Administration operated under the provisions of Act No. 4003 (the Fisheries Act) and Act. No. 2590 as amended, entitled "An Act for the Protection of Game and Fish." In 1934, however, the Fish and Game Administration was placed under the Bureau of Science, with additional facilities for coördinating the administration and research activities. Through the guidance and initiative of this Division the Philippine Government was able to introduce improvements in the fishing industry by the establishment of demonstration stations. In these stations scientific methods of culturing marine and fresh-water fishes and of oysters, and improved methods of fishing in fairly deep waters are being practiced. A fish-preservation station and a pilot canning plant were likewise established for the benefit of the industry.

Philippine ichthyology, which is fundamentally the basis of fisheries work, has received considerable attention from the Philippine Government. The fish collection of the Bureau of Science now contains identified specimens representing 1918 species, a large number of them abundant in Philippine waters and of great commercial importance. The larger forms of economic crustaceans are also represented in the collection of the Bureau of Science by about 100 species. Commercially valuable species of sponges, corals, pearl shells, button shells, trepang, oysters, and other sea products have also been studied and are being given more and more attention and consideration. The biology of certain fishes, mollusks, crustaceans, and other valuable aquatic animals has recently been studied for the formulation of a program for their conservation by the protection of breeders, the rehabilitation of depleted fisheries, and the propagation of fishes that can be raised in ponds or propagated in lakes and rivers. Methods of fishing employed in our waters have likewise been looked into with the end in view of promulgating regulatory and remedial measures.

Fishing banks have, to a certain extent, been surveyed and investigated. Sources of water pollution have also been determined.

As a result of these investigational activities and studies of the Bureau of Science and the University of the Philippines, regulatory measures have been promulgated for the protection of certain species of fish and other aquatic resources and for the prevention of their depletion.

In the twenty years since their introduction by the Japanese, two additional methods of fishing, the beam trawl and the *muro-ami*,[2] are now quite extensively used in fairly deep waters of Manila Bay, Lingayen Gulf, the Gulf of Ragay, the Visayan Sea, and in the waters of Palawan, Mindanao, and the Sulu Archipelago. Recently the Japanese also introduced deep-sea fishing of tuna, especially the skipjack, in the waters of Zamboanga, of the Sulu Archipelago, and of northern and southern Mindanao.

CONDITION OF PHILIPPINE FISHERIES

The present condition of Philippine fisheries may be described briefly and generally as follows. Lake and river fisheries show signs of depletion. Valuable species of fresh-water fishes, crustaceans, and mollusks are no longer as abundant as they were in the past. These bodies of water require artificial replenishing, reconditioning, and improvement in order to be more productive. Shallow coastal fisheries, including small bays and bayous, are apparently declining markedly in productivity. This falling off in the productiveness of Philippine fisheries is due primarily to two factors: (1) the continuous use of destructive fishing gear and fishery methods and the catching of young and immature individuals; and (2) the widespread use of explosives and fish poisons in catching fish.

Pelagic and offshore fishing areas of the open seas show great promise of commercial productivity. But because these fishing grounds have not yet been properly exploited, no statement can be made at this time concerning the Philippine pelagic and offshore fisheries.

PRESENT TENDENCY IN PHILIPPINE FISHING

With the growth in population and the development of land resources, as well as the extension of transportation facilities, capitalists are now beginning to invest in fishing enterprises in the Philippines. Fishermen are beginning to improve their methods of fishing. Even the antiquated fish corral (*baklad*) which in the past was used only in rivers, lakes, or shallow waters, has been developed, and now such fish traps, sometimes costing no less than 3000 pesos each, are constructed in Philippine waters as deep as 15 meters, or 50 feet. Trawl lines or set lines (*kitang*) were enlarged and adapted for use in deeper waters. Trolling (*sibid-sibid*) is also developed to catch fairly large numbers of pelagic fishes. Gillnets (*pante* and *bating*) are likewise adapted for use in deeper waters. The seine reached a unique development in the form of a round haul seine (*lawag* or *sapiao*) which, in conjunction with the use of luminous lights to attract schools of pelagic fishes, is capable of catching at times large quantities of anchovies and clupeids and occasionally young mackerels in the open seas. An outfit of this net costs no less than 8000 pesos. Another improved form of seine is the purse seine (*kub-kub*), also used in pelagic fishing in fairly deep water, catching principally mackerels and clupeids. An outfit of this kind costs about 3000 pesos. Hooks and lines are now used in waters as deep as 50 to 60 fathoms.

Another distinct stride in the improvement of the aforementioned fishing gear is the replacement, to a certain extent, of frail man-powered bancas

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[2] *Muro-ami* is the same as Japanese trap net.

(small wooden boats or dugouts) by more seaworthy craft that can venture much farther away from shores. These outfits are towed by motor launches to and from the fishing grounds. In this way the catch is taken more quickly to market. The general tendency of the Filipinos is gradually to replace fishing gear used near the coasts and in shallow waters with gear adaptable to deeper waters of the sea.

The introduction of two kinds of Japanese fishing gear, the Japanese trap net (*muro-ami*) and the Japanese beam trawl (*utase*), has attracted more capital to the fishing industry. In December, 1938, the amount of capital actually invested in powered fishing vessels of more than three tons gross and other equipment amounted to 1,248,000 pesos.

In view of the obvious depletion of the inshore fisheries, attention is now being directed to fishing in the deeper waters of bays, gulfs, and other sheltered waters of the Philippines with the apparent tendency of venturing farther out in the open seas where rich offshore and pelagic fisheries are now to be encountered. This type of fishing can be developed further to cover the fishing areas beyond the three-mile territorial waters.

URGENT PROBLEMS OF THE PHILIPPINE FISHING INDUSTRY

Among the important needs and problems confronting our fishery industries are: (1) the increase of the production of fish and fishery products; and (2) judicious commercial utilization, and conservation, of these aquatic resources. With regard to fish and fishery products the Philippines is at present far from self-sufficient; during the twenty-year period from 1916 to 1935, importation of fish and fishery products exceeded that of exportation of such commodities by 186,087,453 kilograms valued at 61,702,216 pesos, a yearly average of 9,304,373 kilograms, or 3,085,111 pesos.

A computation submitted by the writer in 1938 to the Committee on Foods of the National Economic Council of the Philippines conservatively estimated the consumption of fresh fish by the Filipinos at 965,000 tons a year, while the commercial production (fresh fish) was estimated at 507,694 tons a year, showing that the Philippine production of fish and fishery products at present is far below its yearly consumption.

INCREASE OF FISH PRODUCTION

Can the Philippines increase her production of fish? Japan was able to increase fish production by 240 per cent through a determined effort and systematic program of stimulating and encouraging ocean fisheries for a period of twenty years (1915–1936). This was accomplished primarily by the use of efficient and effective methods of fishing and by persistent extension of fishing operations to areas in the deep waters of the open seas. Japan has pushed its deep-sea fisheries even to waters beyond the three-mile zone of her territorial waters. As has been noted elsewhere in this paper, the Philippines offshore and pelagic fisheries have not as yet been subjected to deep-sea fishing activities. It is, therefore, essential that in order to increase the yearly production of fish in the Philippines, the Philippine Government should encourage the utilization and development of such fisheries by attracting the necessary capital. In order to do this, the Government should demonstrate to the public that such fishing enterprises are practicable and profitable. One of the handicaps that prevents the prosecution of deep-sea fishing in the Philippines is lack of fishermen trained and skilled in this type of fishing. It is in this particular endeavor that the Philippines should have mutual understanding and close coöperation with her neighbors. The present arrangement as provided for in the Fisheries Act (Act 4003) of allowing a certain number of qualified alien fishermen to fish in Philippine waters is of mutual advantage to the industry and to the citizens of the countries concerned. In the early part of 1939, about 600 Japanese fishermen were licensed to fish in Philippine waters, and thus to follow an occupation in which they have been trained. The Filipinos benefit from this arrangement by acquiring experience from the Japanese fishermen. Since 1932 or a little earlier, a goodly number of Filipino fishermen have already learned how to use *utase* and *muro-ami,* and to date there are approximately 1800 Filipino fishermen engaged in fishing with such gear. About two years ago the first real pelagic fishery was started by the Japanese fishermen of the Sea Foods Corporation engaged in the catching and canning of tuna, especially the skipjack (*Katsuwonus pelamis*). This corporation had a force of 35 expert Japanese fishermen, and in addition employed Filipino student fishermen in tuna fishing. To date this corporation has in its employ 60 Filipino fishermen, who are now fairly well acquainted with the methods used in tuna fishing in the open waters of northern Mindanao, Zamboanga, Basilan, and the Sulu Archipelago. The average yearly catch of the Sea Foods Corporation at Zamboanga is 300,000 kilos.[3] Undoubtedly this production can be materially increased by more extensive fishing, as the skipjack, bonito, and yellowfin are abundant in Philippine waters.

Increased production of fish through the use of more effective methods of fishing is indicated by records of catch in Manila Bay. By the use of beam trawls operated by motor launches the catches in Manila Bay from 1933 to 1936 show a substantial yearly increase, as shown in table 1.

TABLE 1

FISH CAUGHT IN MANILA BAY BY BEAM TRAWLS FROM 1933 TO 1936

Year	Kilograms	Increase over preceding year (kg.)
1933	4,710,000	
1934	6,650,000	1,940,000
1935	10,670,000	5,960,000
		4,020,000
1936	13,020,000	8,310,400
		6,370,400
		2,350,400

Increased production of fish commodities may also be accomplished by resorting to the following:

1) *Improvement of fishponds for bañgos.*—Bañgos, or milkfish (*Chanos chanos* Forskål), is one of the most important commercial fish in the Philippines. Because it is raised in controlled ponds it becomes available the year round, even during inclement weather when other fish are absent in the markets. It has been estimated that the bañgos industry in the Philippines is worth not less than 50,000,000 pesos. The total area now devoted to privately owned bañgos fishponds is 47,330 hectares, while that of the government-leased fishponds is 10,024 hectares, or a total of 57,354 hectares. Allowing a yield of 1000 marketable bañgos of 400 grams each per hectare, with two harvests a year, our fishponds should be capable of yielding 44,883,200 kilograms a year. This production can be materially increased by enlarging the acreage of fishponds through the conversion of the undeveloped mangrove swamps in various parts of the Philippines, and by scientific methods of the culture of algae (*lumut*), which is the primary food of the fish, as well as by

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[3] 300,000 kilos = 300 tons.

the use of scientific methods in the handling of fish fry and fingerlings, the two most critical stages in the life cycle of bañgos.

2) *Extensive culture of fresh-water fish.*—The newly acquired and introduced gourami, *Osphronemus gouramy* Lacépède, from Java, which in the brief period of twelve years has shown great promise as a culture fish in the inland waters of the Philippines, should be introduced in other regions. The introduction of other species of fish suitable for propagation in the Philippines would help increase fish production.

3) *Restocking of lakes and rivers.*—The income from the fisheries of Lake Taal (Bombon) in Batangas Province, which in the past gave the municipalities of Lemery and Taal not less than 30,000 pesos yearly, has, owing to depletion, been reduced to 16,000 pesos. The same is happening in the fresh-water lake of Naujan in Mindoro, Laguna de Bay, in Laguna and Rizal provinces, and Lake Mainit, in northern Mindanao. The fresh-water streams of Ilocos Norte, Ilocos Sur, and La Union provinces, which yielded hundreds of thousands of pesos' worth of *ipon* (fry of Gobiidae and Eleotridae), are now markedly depleted. The stocking of some fresh-water lakes in the Philippines with carp (*Cyprinus carpio* Linnaeus) and the raising of gourami in fresh-water ponds have demonstrated the advisability of thus increasing fish production.

4) *Increase of salt production.*—The program of increasing fish production should be reinforced with efforts to increase the output of salt, as large quantities of this preservative are required for the preservation of excess catch of fish. Therefore, the development of more salt beds in various parts of the Philippines should form part of the program to increase fish production.

Judicious Commercial Utilization of Aquatic Resources

To withdraw large quantities of fish from any given bank, man tends to resort to the easiest methods of catching or collecting, without regard to their possible destructiveness. This is a problem by itself for the Philippine Government to study in connection with the regulation of the employment of destructive methods or the prohibition of the most destructive ones. The most precarious situation confronting the Philippine fishing industry is the apparent increase in the illegal use of explosives and fish poisons in the catching of fish. Undoubtedly the widespread use of explosives is inimical to the fisheries of the Philippines. Fishing banks in coastal waters are more adversely affected than those in the deeper waters, because shallow waters are usually and generally the haunts of larval fishes, and not infrequently the spawning banks of common edible fishes of commercial importance. Moreover, explosives destroy the natural habitat (surroundings) of not only the food fishes but also the organisms upon which they depend for their sustenance. Hence, the dynamiting of fishing banks results not only in the wholesale killing of fish, a very small proportion of which are captured or rescued, but also in the driving away from the affected fishing banks of the survivors of the explosions. Recently, it has been reported that the use of explosives in the Philippines is also becoming excessive in the open deep waters. It is but natural that pelagic fishes which travel in large compact schools are the ones most affected. Unfortunately these fishes include the bulk of the commercial food fishes, such as sardines, herrings, mackerels, tuna, pompanos, and barracudas.

Fishery Conservation

GENERAL PRINCIPLES FOLLOWED IN THE FORMULATION OF PROGRAMS

"Conservation of a marine fishery resource is a balance between the fish taken from the population by man or other means and the fish added to the population by natural reproductive process. Regulatory measures, therefore, are attempts to create this balance."[4] Regulatory measures to conserve fishery resources are fairly well standardized or systematized throughout the world. These measures include at least five primary features: (1) A close season, usually in force during the spawning season or the peak of this season, if known. The catching, especially on a commercial scale, of spawning and brooding fish should be avoided as much as possible. (2) Minimum size limits based upon size at sexual maturity. The catching of undersized and young or sexually immature individuals should be avoided. It should be borne in mind that replacement of the adults comes from the younger groups. (3) Protection of areas which are known to be fish nurseries. Spawning, brooding, and/or feeding grounds of larval forms should be set aside as fish sanctuaries. (4) Restriction or prohibition of certain types and sizes of gear used in catching fish, especially on a commercial scale. Only methods that will insure the easy passage of immature individuals, so that the species is given the chance to propagate at least once or twice in its life time before its capture, should be recommended in commercial fishing. Meshes of nets or openings of traps should be standardized, on careful study of the average size of the fish at sexual maturity. (5) Avoidance of unnecessary destruction of fish for nonprofitable undertakings should also be avoided. Indeed, the greatest obstacle in conservation work is the "point of view of many individuals that the sea is so extensive and the fish population so enormous that any puny inroads which man might make into the supply are negligible; therefore, why be concerned about the destruction of a few millions of small fishes?" Experience has taught us, however, that this attitude is erroneous, and that conservation of the supply is more important than attempts at the rehabilitation of depleted or denuded fisheries.

An ironclad rule to be followed in the formulation of programs for fishery conservation is not easily arrived at, in view of the fact that each species requires different treatment and approach. However, certain fundamental considerations may be followed in carrying on uniform investigational work along the lines of fish conservation. Such points are:

First: Systematic studies of fishes (ichthyology). The species of fishes composing a given fishery must be known before the biology of the fisheries in question can be studied. As has already been pointed out, each species has its own distinct characteristics or habits.

Second: Study of the condition of fisheries.—The condition of the fishery includes the degree of abundance or scarcity of fish in a body of water, bank, or portion thereof. When the catch per unit of effort persistently falls below a certain average level of abundance, the fishery in question no longer insures a profitable business operation. At this juncture the fishery is said to be depleted. By abundance is meant the maintenance of a certain average of catch per unit of effort or gear whereby the productivity of the fishery could guarantee the operation of a profitable business enterprise. The average level of abundance of a given fishery may be ascertained by the following methods:

1) *Statistics of catch per unit of effort or gear.*—When a fishery is exploited commercially, it is natural to find that the catch per unit of effort is high. In the course of commercial exploitation the catch naturally tends to go down gradually until a certain ratio of abundance which represents a balance between the rate of multiplication and the rate of catching the fish is reached. This level of abundance, which may be termed average level of abundance, should remain more or less constant. Other things being equal, should the

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[4] G. H. Clark, "The California Trawl Fishery and Its Conservation," *California Fish and Game*, 22:25 (1936).

number of fish taken exceed the number of young produced, the catch will eventually fall below the average level of abundance and the fishery becomes depleted. It is necessary to study catch per unit of effort yearly for at least ten years, because sometimes the increase or decrease of catch may be due only to the degree or intensity of fishing.

2) *Statistics of percentage of young or immature fish in the catch.*—Types of fishing gear may be grouped under (*a*) nonselective fishing gear and (*b*) selective fishing gear. Nonselective gear catches fish irrespective of species or size-groups present in a given fishery. Selective gear catches fish consisting mostly of either young or mature, or catching only or mostly one or two species of fish. The continual increase of the percentage of young found in the catch of nonselective fishing gear from year to year would show that the adult fish are getting scarcer; such increase is a sign of depletion of a given fishery. The persistent presence of more immature fish in the catch is an indication that the replacement of adult by the young is retarded by overfishing. It is essential that the computation of the ratio between the young in the catch be based on each unit of effort.

3) *Survey of the abundance or scarcity of food of fish composing a given fishery.*—The feeding capacity of the food fishes should be ascertained. Likewise, the development and reproduction of animals and other sources of food for the fishes should be studied. An estimate of the necessary food of the fishes to sustain an average level of abundance should be ascertained. Other things being equal, depletion of the food of fishes would naturally bring about scarcity of the fish themselves. A formula that may be used in ascertaining the necessary amount of food for a given population of food fishes should be worked out by actual observations from a given fishing area or bank. The importance of the qualitative and quantitative study of the plankton as well as its distribution in our lakes, rivers, and seas should not be overlooked.

Third: Study of the migration of fishes. The study of the periodic movements or migrations of fishes is essential in the formulation of regulatory measures for their protection and conservation. Areas where fishes breed, spawn, or brood, and the feeding grounds of larval fishes, should be protected from the effect of destructive methods of fishing. Places where fish gather in large compact schools during the critical stage of their development should be given similar protection. Such areas can be determined only after a thorough study of the migratory habits of our commercial fishes.

Fourth: Study of rate of growth, age, and sexual maturity of fishes. The study of the rate of growth, age, and sexual maturity of fishes is undertaken also for the purpose of obtaining information necessary for fishery conservation. Information on the rate of growth of fishes is essential in connection with the determination of the age and size at sexual maturity. It is an established fact that in order to conserve a species, immature individuals should not be caught, but only fishes of a group size representing individuals that have spawned at least once in their lifetime. Hence, by knowing the size at sexual maturity regulatory measures may be formulated for the protection of immature individuals. For example, standardization of mesh openings of nets, or openings between slats of fish corrals or other forms of traps, may be based upon the size of each species of fish at sexual maturity. Moreover, depending upon the size at sexual maturity of the fish, a minimum size for each species may be determined, and to catch, possess, purchase, offer for sale any fish measuring below such minimum size be declared illegal.

In the event that fisheries become depleted, it is necessary to establish a close season and to prohibit the commercial catching of depleted species during a period necessary to insure the replacement of individuals of marketable size groups taken. Close seasons must necessarily be based on the period of spawning and age at which most, if not all, of the individuals of a species attain their sexual maturity. Usually it would be safer and more advantageous to add at least two years to the age at which sexual maturity is attained. In this way the fish are assured of the chance to spawn at least twice before they are captured, and a sufficient number of young to replace the adults caught. A close season too short for obtaining the necessary replacement and rehabilitation of depleted fishery would not be futile; on the other hand, one too long would be inimical to the public interest, since old fishes would die upon reaching the maximum age. It is better to utilize mature fish just at their right age.

Fifth: Study of the spawning season and the drift of the spawn. The study of the spawning season of fish is very important in fish protection and conservation. The spawning areas should be considered in the light of the spawning season of the fish to be protected. In making provisions for the protection of the spawning areas the drift of the spawn should also be studied, as there would be no use of protecting the breeding grounds if the eggs and larvae are drifted away soon after oviposition and hatching. This is especially true with respect to pelagic (surface-floating) eggs. The most effective way is to make a survey of the nurseries of the fish and ascertain the movements of their spawn after oviposition and hatching. Local areas where eggs and larvae are found should be protected from the operation of fine-meshed nets.

Sixth: Study of the brooding season of the fish. With respect to certain species of fish, the brooding season is considered more critical than the spawning period. At least a part of this period, in addition to the spawning season, or a part thereof, if and when necessary, should be included in the close season. Fishes which incubate their broods in their mouths constitute the best example of fishes which should be thus protected.

Seventh: Study of some ecological factors tending to modify the passage of year or age classes in a fishery. In a given fishery there occurs a periodic abundance or scarcity of certain year or age classes or size groups. This is influenced by certain ecological factors, such as temperature, salinity, currents, amount of food, and season of spawning. Abundance of adults may be modified by the occurrence of a dominant year or age class. The study of the spawning habits of fish is also important. For instance, if a certain species spawns but once in its lifetime, like most of the salmons, the fish must be given greater protection, for the chance of reproduction is limited. Or, if the fish spawns but once a year, or at closer intervals, distinct dominant age classes would be present in the runs. It is important to know the spawning intervals. If a certain species spawns once in five years, a dominant year class or age class would occur every five-year period. Once this is ascertained, it would be possible to predict the appearance of undersized fish in the runs, and thus to determine the time when the fish are in need of protection.

A workable method of determining the appearance of dominant year classes or size classes in the runs of fishes would be to measure a given sample consisting of a reasonable number of fish periodically (weekly or monthly) as the case may be, and from season to season for several years and to plot the measurements on a function of time. The graphs produced would show the frequency of dominant year classes, or size classes in a given fishery.

CONSERVATION OF PHILIPPINE FISHERIES

Philippine ichthyology.—Systematic ichthyology, the fundamental basis of fishery investigations, has not been neglected in the Philippines, as is shown by the fact that 1918 known species of fish distributed under 31 orders, 205 families, and 602 genera are listed in the check list compiled by Hilario A, Roxas and Claro Martin (1937). Credit is due to such outstanding authorities on Philippine ichthyology as Dr. A. W. Herre and Mr. Alvin Seale, both formerly of the Philippine Bureau of Science; and Dr. David Starr Jordan, R. E. Richardson, B. W. Evermann, C. H. Gilbert, H. W. Fowler, C. L. Hubbs, G. Myers, L. Radcliffe, and H. M. Smith of the United States. Credit is also due to Philippine workers such as H. R. Montalban, H. A. Roxas, C. Martin, A. F. Umali, J. Montilla, G. J. Blanco, and others, as well as to the early workers from abroad, notably Weber and Beaufort, Tate Regan, Franz Steindachner, Marion de Ponce (1822), John Jacob, Heckel (1840), Johannes Müller (1843), Richardson and Gray (1846), Kaup (1858), Günther (1859), Sauvage (1878–1880), A. B. Meyer (1865), and Fr. Casto de Elera (1895).

It appears now that Philippine ichthyology is not much of a problem, although the races composing the fisheries remain to be studied. The determination of these races in relation to the migratory habits of the pelagic fishes that from all indications constitute the bulk of commercial fisheries is most important. From such studies we may learn whether the species or races of fish found on one fishing bank or in waters of one country are the same as, or different from, those found on another bank or in waters of other countries. Again, attention is called to the necessity of enlisting the coöperation of neighboring nations of the Pacific in connection with such studies so that rules for the protection, conservation, or commercial utilization of these resources may be promulgated for the mutual benefit of the countries concerned.

Statistics on Philippine fisheries.—The gathering of statistics of catches of commercial fishes in the Philippines started only in 1933, immediately after the approval of Act. No. 4003, known as the Fisheries Act. These statistics are, however, still too inadequate to serve as a basis for conclusions with respect to the actual conditions of the fishing grounds of the Philippines. The only statistics of catch available are those of licensed commercial fishing boats of more than three tons gross, operating in Manila Bay, Lingayen and Ragay gulfs, Visayan and Samar seas, and waters around Palawan, northern Mindanao, and the Sulu Archipelago. Records of catch from Manila, Lingayen and Ragay gulfs, and Visayan and Samar seas are mostly those of ground fishes taken by the Japanese beam trawls. In the waters of Palawan the records of catch are those of the coral fishes, primarily the pomadasids and acanthurids, taken by Japanese trap nets. From the waters of northern Mindanao and the Sulu Archipelago are taken pelagic fishes, notably the skipjack and other species of Thunnidae, by hook and line, used especially in the commercial catching of tuna. Statistics of catch made by round-haul seines, purse seines, and gill nets are being gathered, mainly the anchovies, clupeids, and mackerels.

The percentage of young in the catches of round-haul seines, purse seines, gill nets, and beam trawls is being studied. The percentage of young in the catch of drag seines and fish corrals used in the commercial catching of catfishes (Ariidae) has been studied in connection with the determination of the condition of this fishery in Laguna de Bay.

Studies on fish migration.—The studies made on the migratory habits of fishes in the Philippines are confined, so far, to the catfishes, *Arius* spp., of Laguna de Bay; *Caranx marginatus*, *Caranx ignobilis*, *Chanos chanos*, *Mugil* spp., *Lutjanus argentimaculatus*, and *Megalops cyprinoides* of Lake Taal, Batangas Province; *Mugil dussumieri* of Lake Naujan, Mindoro; and the *ipon* (fry of Gobiidae and Eleotridae) of the fresh-water streams of northern Luzon and northern Mindanao.

Studies on the rate of growth, age, and sexual maturity of fishes.—Studies on the rate of growth and age groups or size groups have so far been made of

Arius spp. and species of Gobiidae in Laguna de Bay. Similar studies are being pursued on the following species: *Sardinella perforata, S. fimbriata,* and *Rastrelliger brachysomus.* Size at sexual maturity has been determined in *Arius* spp., *Therapon plumbea, Glossogobius giurus, Mirogobius lacustris, Ophicephalus striatus, Gulaphallus mirabilis, Johnius aneus, Gerres filamentosus, Neimpterus japonicus, Saurida tumbil, Sphyraena jello, S. obtusata, Sardinella perforata, S. fimbriata, Rastrelliger brachysomus, R. Chrysozonus,* and *Leiognathus equulus.* Such studies have also been made on some species of mollusks of commercial value.

Studies on the spawning and brooding season of fishes.—Contribution to the knowledge of spawning or brooding habits of Philippine fishes are few, so far, being limited to *Arius* spp., *Therapon plumbea, Glossogobius giurus, Mirogobius lacustris, Amphacanthus oramin, Sicyopterus lacrymosus,* and species of *Sardinella, Rastrelliger,* and *Stolephorus.* The drift of the eggs or spawn of marine fishes is being studied in connection with studies on plankton distribution in Manila Bay.

Remedial and regulatory measures so far promulgated in the conservation of Philippine fisheries.—The following remedial and regulatory measures have so far been promulgated, as a result of studies made on Philippine fishes and fisheries.

1) Act 2590, providing regulations for the protection of game and fish. This act authorizes the Secretary of Agriculture and Commerce, subject to the approval of the Governor General, to establish close season for fish or shellfish, and prohibits the placing, discharging, or depositing, or passing or placing where it can pass, of any material substance deleterious to fish life.

2) Act 4003, or "Fisheries Act," provides rules and regulations to amend and compile the laws relating to fish and other aquatic resources of the Philippine Islands, and for other purposes.

3) Commonwealth Act 115, amending sections sixty-seven, sixty-nine, and seventy of Act numbered four thousand three, otherwise known as the "Fisheries Act."

4) Commonwealth Act 297, amending section seventy of Act numbered four thousand three, known as the "Fisheries Act," as amended by Commonwealth Act numbered one hundred fifteen.

5) Fish and Game Administrative Order No. 2, providing regulations for deep-sea or offshore fishing.

6) Fish and Game Administrative Order No. 3, providing regulations for the conservation of dalag (*Ophicephalus striatus*), *Kanduli, Arius* spp., and *banak* (*Mugil* spp.). This order prohibits the catching of kanduli 16 centimeters or less in length and provides a close season for the catching of kanduli by drag seines during a period of three months, from April 16 to July 15 of each year. This order prohibits further the catching of immature and spawning mullets (*Mugil* spp.).

7) Fish and Game Administrative Order No. 11, providing for rules and regulations for the protection of marine mollusca.

This order permits the taking of shells of certain sizes. For *Pinctada maxima,* 19 centimeters (outside long axis measurement taken at right angle to the base); for *Pinctada margaritifera,* 11 centimeters, measured as the preceding species; *Trochus niloticus,* 8 centimeters (measured as *T. maximus*); *Trochus noduliferus,* 7 centimeters; *Turbo marmoratus,* 9 centimeters (measured as *Trochus*).

8) Fish and Game Administrative Order No. 13, establishing close season from November 15 to March 15 of each year for the conservation of sardines and herrings and other pelagic fishes of the Visayan Sea and for other pur-

poses. The taking of the young or fry and sexually mature sardines and herrings during this close season is prohibited.

In addition to the administrative orders promulgated as described above, various recommendations for the protection and conservation of other fishery resources of the Philippines have been formulated and are now pending promulgation. The most important of these are for the conservation of the fresh-water lake fisheries, especially the migratory species like the ipon (fry of gobies and eleotrids) fisheries, the fry of bañgos (*Chanos chanos*); and for the siganids and teuthids, the sardines, and the ground fishes of Manila Bay.

PROBLEMS OF FISHERY CONSERVATION IN THE PHILIPPINES

Problems of fishery conservation in the Philippines may be discussed under two categories, namely: (1) conservation of fishes that are residents of Philippine waters, and (2) conservation of migratory fishes that are habituated to long-range migrations which may cover waters of other lands in their sojourn. The migratory movements of the resident fish are confined in Philippine waters. The first problem may be solved at home; the second requires the coöperation of neighboring nations of the Pacific.

Conservation of fishes resident in Philippine waters.—The important commercial species of fishes known to be residents in the Philippine waters are listed below in Appendix A, arranged by family.

The problems relating to the conservation of fishes resident in Philippine waters are being gradually solved by local workers. Accomplishments along this line are discussed in this paper under the subject of "Conservation of Philippine Fisheries." However, attention is here called to the following outstanding problems which should require immediate solution. In an effort to conserve the important species of *Chanos chanos* Forskål (Chanidae), two things must be done: (1) the supply of its fry must be conserved, and (2) spawners and breeders must be protected.

The catching of bañgos fry is made during a definite period from March to June or July of each year. The bañgos fry is caught from the shallow waters of sandy coasts, mouths of rivers, mud flats, and estuaries. Since the catching of the larval forms of this fish can hardly be regulated because of the demand for them for stocking the nearly 58,000 hectares of fishponds, it has been suggested that in order to conserve the supply of this fry the breeders or spawners be protected and fish sanctuaries established at certain strategic points in Philippine waters. Spawners of this species are found in deep waters of the sea, usually in sheltered coves, bays, and gulfs. Recently it has come to the attention of local workers on fishery that large numbers of spawning bañgos are taken annually, sometimes by the use of dynamite. This practice is illegal and every effort is being exerted to stop it. The wholesale catching in lakes or their outlets of sexually mature bañgos which are usually about to breed, as in Taal Lake, Batangas, and Naujan Lake, Mindoro, is being regulated. These bañgos which make the seaward migration are captured in fish corrals constructed across the entire width of the outlets of lakes. In order to protect the supply of bañgos fry, the establishment of closed areas or fish sanctuaries both for the spawners and the fry is essential. Certain portions of the mouths of rivers, including contiguous waters of the coast, especially those which are connected with large lakes where spawning bañgos make yearly seaward migration and where fish fry take shelter and feed, should be established as fish sanctuaries.

The importance of the bañgos fry industry can be gauged by the value of the bañgos industry in the Philippines. It is estimated that not less than 50,000,000 pesos are invested in this industry. At least 7000 people own fishponds covering an aggregate area of 57,354 hectares. Moreover, about 100,000 pesos in annual license fees are paid to municipal governments by the concessionaires for the collection of bañgos fry from various municipal waters in the Philippines. This amount does not include that which is annually paid in the form of internal revenue or sales taxes.

The most important species of mullets have migratory habits, like the bañgos *Chanos chanos* (Chanidae). Their young enter fresh-water lakes and rivers, and mature individuals return to the sea during the breeding period. These species of mullets can, therefore, be conserved or protected from depletion by the same means as are suggested for the bañgos. Mullets that are habitually marine are at present in no danger of depletion, because the methods in general use for catching them have not proved destructive. However, vigilance with respect to the use of dynamite must be exercised also in the protection of the mullets.

Fishes belonging to the families of Epinephelidae, Serranidae, Lutjanidae, Pomadasidae, Acanthuridae, Scianidae, Hepatidae, and Amphacanthidae are at present quite abundant in the Philippine waters. They are caught in large quantities in fish corrals, by hook and line, and in the Japanese fish traps (*muro-ami*). These methods are apparently not destructive, because the bulk of their catches consists of mature individuals. However, the operation of the Japanese fish traps is closely watched, because of the alleged use of the dynamite in connection with its operation. The Amphacanthidae require protection during their breeding season. Because of the habit of the spawners of these fish to go in schools in shallow waters where they oviposit on rocks and other objects in the bays, coves, and gulfs, the promulgation of a close season during the peak of their spawning activity has been recommended.

Problems of conserving fishes habituated to long-range migrations.—Fishes which have the habit of migrating from zone to zone of great latitudinal range are found in the territorial waters of the Philippines during certain periods, and in waters of other countries at other times are pelagic and believed to constitute the most important ocean fisheries. In 1929 Japan's estimated annual production of fish and other ocean products was 5,150,000 tons, valued at 500,000,000 pesos, which is more than one-fourth of the entire world production. Most of these sea products belong to the pelagic and offshore fishes, fishing having been carried on chiefly in seas less than 200 meters (100 fathoms) deep, except for the tuna and bonito, which are taken from much deeper waters.

Because of the migratory habit of these pelagic fishes their exploitation and conservation in the Pacific area require the joint effort of neighboring nations.

The most important phase of the study of the migratory habit of pelagic fishes is in the determination of their latitudinal and bathymetrical migrations, knowledge of which is essential both for purposes of commercial exploitation and of fishery conservation. Are the *tamban, Sardinella longiceps* Bleeker, or the *tunsoy, Harengula moluccensis* Bleeker, which are found in abundance in the Visayan Sea during certain periods of the year, the same species or races as are found at other times in the Samar Sea, Sulu Sea, China Sea, or other waters of the Philippines? Or do these sardines appear or disappear periodically from the Visayan Sea or other Philippine waters without undergoing long-range latitudinal migration but only making bathymetrical movements? If they resort to the latter type of migration, how far do they move below the surface of the ocean? The same inquiries may be made concerning whether or not the oceanic bonito (*Euthynnus vaito* Kishinouye), the skipjack (*Katsuwonus pelamis* Linnaeus, or the yellowfin (*Neothunnus macropterus* Schlegel), which appear in large numbers in Philippine seas, are the same species or races as those found in the waters of Japan, Borneo, Australia, and other neighboring countries.

Information on these points is essential in the prosecution of proper methods for their commercial catching as well as in the formulation of programs for their protection and conservation.

The most important Philippine species representing this group are listed below in Appendix B.

His Excellency the President of the Philippines has wisely said, "Never before could it have been said as truly as it can be said nowadays that every country is in the world and has to live with the world. The radio and the aeroplane have made them interdependent in their economic life."[5] In matters of fish and fishery products the Philippines deals with various countries of the world. Of the Pacific nations, we deal heavily with the United States including the Hawaiian Islands, and with Japan, and to a certain extent with China and the East Indian countries. The Philippine overseas trade in fishery and aquatic products with these countries is indicated below. The important fish products that the Philippines buys from other Pacific countries (computed as yearly average, from 1932–1936) are:

Canned sardines

United States: 3,550,086 kilograms valued at 682,316 pesos
Japan: 2,212,172 kilograms valued at 309,193 pesos

Canned salmon

United States: 725,604 kilograms valued at 197,161 pesos
Japan: 237,585 kilograms valued at 47,775 pesos
Canada: 215,298 kilograms valued at 43,859 pesos

Canned mackerels

United States: 478,436 kilograms valued at 82,211 pesos
Japan: 300,572 kilograms valued at 45,507 pesos

Smoked or cured fish and shellfish

United States: 341,641 kilograms valued at 118,180 pesos
Japan: 1,346,543 kilograms valued at 249,666 pesos
China: 225,040 kilograms valued at 86,394 pesos

Canned shellfish

United States: 1,461,222 kilograms valued at 280,376 pesos
Japan: 110,240 kilograms valued at 23,579 pesos
China: 19,756 kilograms valued at 7,056 pesos

Fresh fish

United States: 60,855 kilograms valued at 33,920 pesos
Japan: 22,280 kilograms valued at 18,398 pesos
Canada: 3,688 kilograms valued at 1,820 pesos
China: 164, 515 kilograms valued at 33,187 pesos

On the other hand, the Philippines sells to the Pacific countries the following fish commodities:

Dried, smoked or cured bêche-de-mer (yearly average from 1933–1936)

China: 72,790 kilograms valued at 19,718 pesos
British East Indies: 108,287 kilograms valued at 51,544 pesos
Hongkong: 31,088 kilograms valued at 6,934 pesos
Hawaii: 144,242 kilograms valued at 15,674 pesos

Trocha, green snail, window shells, and others (yearly average from 1933–1936)

United States, Guam and Hawaii: 5,862 kilograms valued at 2,857 pesos
Japan and Japanese Oceania: 258,215 kilograms valued at 96,142 pesos
British East Indies: 19,398 kilograms valued at 3,276 pesos
Hongkong (1934 only): 3,708 kilograms valued at 1,000 pesos

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[5] M. L. Quezon, President of the Philippines, Commencement Speech, University of Philippines, April 4, 1939.

Pearl shells (mother-of-pearl)

United States (Average from 1916–1935): 53,718 kilograms valued at 46,549 pesos
Japan (Average from 1933–1935): 15,098 kilograms valued at 3,222 pesos
British East Indies (Average from 1916–1935): 119,545 kilograms valued at 82,218 pesos
Hongkong (1935 only): 3,588 kilograms valued at 2,783 pesos

Tortoise shells

British East Indies (Average from 1916–1935): 823 kilograms valued at 14,597 pesos

Shark fins

British East Indies (Average for 1916–1935): 7,484 kilograms valued at 1,649 pesos

The problems, therefore, of the wise utilization and conservation of these ocean resources of the Philippines may be regarded as of international concern, requiring at least close coöperation among Pacific nations. These problems need the serious attention of the governments concerned, not only because money and expensive apparatus and other equipment are necessary for their solution, but also the employment of experts in such lines as ichthyology, oceanography, navigation, planktonology, fisheries biology, fisheries technology, and other branches relating to the study of aquatic resources.

RECOMMENDATIONS

It has been noted in the present paper that the most urgent problems now confronting the Philippine fishing industry are the need for increased production of fish and fishery products and an effective program in conserving these fishery resources.

The need for increasing fish production in the Philippines is made conspicuous by the following facts: (*a*) The Philippines still imports large quantities of preserved and fresh fish to meet her yearly needs. (*b*) The Philippine Government, in an endeavor to provide her people with cheaper fish protein commodities which suit the taste of the people, and to effect a more uniform distribution of these fish foods, has recently engaged in the canning of fish through the National Food Products Corporation, a subsidiary of the National Development Company.

In order to bring about increased production, the following are recommended: (1) Investment of more capital in the commercial fishing of the offshore and pelagic fisheries. This may be accomplished by: (*a*) Encouragement of outside capital to be used exclusively in deep-sea fishing administered strictly under the provisions of the present laws of the country. (*b*) Government subsidy to fishing companies engaged in deep-sea fishing. (2) Employment of more skilled fishermen trained in deep-sea fishing. Our Government should, therefore, start at the earliest possible opportunity to train fishermen for deep-sea fishing. A certain number of expert foreign fishermen trained along this line may be taken in to serve as demonstrators or instructors for a definite period of time until the Filipinos are in a position to carry on this enterprise by themselves. In this connection the establishment of training schools for fishermen is urgently needed in the Philippines. With these training schools, it is essential that the Government provide also a well-manned and equipped boat to undertake the survey of offshore fishing areas. (3) Extensive and intensive development of pond culture of fish, crustaceans, and mollusks, such as the bañgos (*Chanos chanos* Forskål), shrimps (*Penaeus* spp.), crabs (*Scylla serrata*), and the introduced fresh-water gourami (*Osphronemus goramy*), all of which have been found to be amenable to artificial cultivation, should be undertaken. Likewise, bays, rivers, and lakes should be properly stocked or replenished with suitable species for propagation.

In order to promulgate a definite government policy on the proper utilization and conservation of our fishery resources, the following are recommended: (1) Centralization and coördination in a well-organized government institution of all matters pertaining to the administration of fisheries, including research and investigational work upon which the formulation of remedial and regulatory measures for the protection of these resources may be based. The most important research work should be directed along the following lines: (*a*) determination of races of fish found in schools or runs of pelagic species; (*b*) migratory habits of these fish; (*c*) statistics on species and on percentage of young in the catch per unit of effort; (*d*) rate of growth, age, and sexual maturity of fishes; (*e*) spawning and breeding habits; and (*f*) other significant aspects of the life history and development of the fish. Among the regulatory measures urgently needed are those which pertain to (*a*) standardization of mesh openings of nets and traps to permit the easy passage of immature individuals of a species; (*b*) establishment of a close season and reserved areas to protect spawners, brooders, and the larval stages of the species; and (*c*) promulgation of minimum size limits for each commercial species based on size at sexual maturity. (2) Strict vigilance and enforcement of the laws of the Philippines against the use of explosives and fish poisons. (3) Creation of an international Fishery Commission among the Pacific nations for the purpose of carrying on coöperative research and investigation, especially that which pertains to the biology of the migratory and pelagic fishes. Members of this commission may exchange ideas and experiences based upon the results of their investigations to the end of correlating and coördinating their problems. Consultation among the members of this Commission may, at least, be held once every two years, so that a definite policy as to the type of problems which should be given urgent attention may be arrived at. For instance, in an effort to ascertain the species or races of pelagic fishes which are habituated to long-range latitudinal migrations, workers of one country may pursue problems similar to those of other countries. Studies on the biology of pelagic fishes which are inhabitants of waters beyond the territorial limit of each country, should be correlated with the results obtained by the various workers of the Pacific area. In this way it may be possible to determine whether the species or race of fish occurring in the waters of one land is the same as that of another country. This would enable the members of the Commission to recommend to their respective governments regulatory and protective measures which are of mutual benefit to the nations concerned. Moreover, this Commission may formulate programs of fishery investigations in the Pacific area which will do away with unnecessary efforts due to duplication of work and serve as a clearinghouse in matters of policy relating to fishery conservation.

APPENDIX A

List of Important Species of Fishes Known to be Residents in the Philippine Waters

1. Chanidae (1 species)
    Chanos chanos Forskål — Milkfish; *bañgos, lumulukso, banglis,* or *zabalo* (large spawners); *kawag-kawag* (fry)

2. Mugilidae (28 species) (Mullet)
    1. *Mugil amarulus* (Cuvier and Valenciennes)
    2. *M. banksi* Seale; *banak*
    3. *M. caeruleomaculatus* Lacépède
    4. *M. cephalus* Linnaeus
    5. *M. ceramensis* Bleeker
    6. *M. crenilabris* Forskål
    7. *M. dussumieri* (Cuvier and Valenciennes); *aliso; balanak*
    8. *M. engeli* Bleeker
    9. *M. joloensis* Seale; *banak*
    10. *M. labiosus* Cuvier and Valenciennes *ludung*
    11. *M. lepidopterus* Fowler
    12. *M. longimanus* Günther; *talilong*
    13. *M. macrolepis* A. Smith; *banak; aguas*
    14. *M. melinopterus* Cuvier and Valenciennes; *banak*
    15. *M. meyeri* Günther
    16. *M. oligolepis* Bleeker
    17. *M. philippinus* Fowler
    18. *M. oligolepis* Bleeker
    19. *M. tade* Forskål
    20. *M. ruthveni* Fowler
    21. *M. seheli* Forskål
    22. *M. strongylocephalus* Richardson
    23. *M. subveridis* Cuv. & Val.
    24. *M. vaigiensis* Quoy & Gaimard; *aguas; banak; talilong*
    25. *Cestraeus goldiei* Macleay
    26. *C. oxyrhynchus* Cuv. & Val.
    27. *C. proboscideus* Günther
    28. *Myxus philippinus* Roxas

3. Epinephelidae (45 species)
    1. *Epinephelus albomarginatus* (Fowler & Bean)
    2. *E. areolatus* (Forskål)
    3. *E. argus* Bloch & Schneider; *turnutulin*
    4. *E. aurantius* Cuv. & Val.
    5. *E. awoara* (Temminck & Schlegel)
    6. *E. bleekeri* (Vaillant & Bacourt); *lapolapo*
    7. *E. boenack* (Bloch)
    8. *E. bontoides* (Bleeker)
    9. *E. caeruleopunctatus* (Bloch)
    10. *E. corallicola* Cuv. & Val.; *lapolapo*
    11. *E. chlorostigma* (Cuv. & Val.)
    12. *E. cyanostigma* (Cuv. & Val.)
    13. *E. diacanthus* Cuv. & Val.
    14. *E. fario* (Thunberg)
    15. *E. fasciatus* Forskål
    16. *E. flavo-caeruleus* Lacépède
    17. *E. fuscoguttatus* Forskål; *garopa*
    18. *E. lanceolatus* Bloch
    19. *E. leopardus* Lacépède
    20. *E. maculatus* Bloch
    21. *E. megachir* Richardson; *baghak, lapolapong liglig*
    22. *E. merra* Bloch; *garopa; lapolapong liglig; kutkut*
    23. *E. nebulosus* Cuv. & Val.
    24. *E. pachycentron* Cuv. & Val.
    25. *E. rhyncholepis* Bleeker
    26. *E. rogaa* Forskål
    27. *E. sexfasciatus* Cuv. & Val.
    28. *E. miniatus* Forskål
    29. *E. morrhua* Cuv. & Val.
    30. *E. sexmaculatus* Rüppell
    31. *E. sonnerati* Cuv. & Val.
    32. *E. summana* Forskål
    33. *E. tauvina* Forskål
    34. *E. undulosus* Quoy & Gaimard; *aboabo; lapolapo*
    35. *E. urodelus* Cuv. & Val.
    36. *Grammistes sexlineatus* Thunberg
    37. *Plectropomus maculatus* Bloch; *lapolapo*
    38. *P. leopardus* Lacépède
    39. *P. oligacanthus* Bleeker; *lapolapo*
    40. *P. truncatus* Fowler and Bean
    41. *Cromileptes altivelis* Cuv. & Val.; *kolapo*
    42. *Variola louti* Forskål; *lapolapong señorita*
    43. *Centrogenys vaigiensis* Quoy & Gaimard
    44. *Anyperodon leucogrammicus* Cuv. & Val.; *lapolapo*
    45. *Chorististium susumi* Jordan & Sale

4. Serranidae (5 species)
    1. *Anthias albofasciatus* Fowler & Bean
    2. *A. cichlops* Bleeker
    3. *A. huchtii* Bleeker
    4. *A. pleurotaenia* Bleeker
    5. *A. squamipinnis* Peters

5. Lutjanidae (37 species) Snappers

1. *Lutjanus argentimaculatus* Forskål; *bakuku; iso*
2. *L. biguttatus* Cuv. & Val.
3. *L. bohar* Forskål; *maya-maya*
4. *L. caeruleovittatus* Cuv. & Val.
5. *L. chrysotaenia* Bleeker; *maya-maya*
6. *L. decussatus* Cuv. & Val.; *buegsang; dolesan*
7. *L. erythropterus* Bloch
8. *L. flavipes* Cuv. & Val.
9. *L. fulviflamma* Forskål; *bitilla; daragdarag*
10. *L. fuscescens* Cuv. & Val.; *camangbuhu*
11. *L. fulvus* Bloch & Schneider; *bambañgin*
12. *L. gibbus* Forskål; *maya-maya; dapak*
13. *L. johnii* Bloch; *bitilla; maya-maya*
14. *L. kasmira* Forskål
15. *L. lineatus* Quoy & Gaimard; *aloñgot*
16. *L. lineolatus* Rüppell
17. *L. lunulatus* Mungo Park
18. *L. lutjanus* Bloch
19. *L. luzonius* Evermann & Seale
20. *L. malabaricus* Bloch & Schneider; *maya-maya; bacbaan; dapak*
21. *L. monostigma* Cuv. & Val.; *maya-maya*
22. *L. nematophorus* Bleeker
23. *L. philippinus* Borodin
24. *L. rivulatus* Cuv. & Val.
25. *L. rufolineatus* Cuv. & Val.
26. *L. sebae* Cuv. & Val.
27. *L. spilurus* Bennett; *maya-maya*
28. *L. vaigiensis* Quoy & Gaimard; *tapako*
29. *L. vitta* Quoy & Gaimard; *alañgot; maya-maya*
30. *Etelis carbunculus* Cuv. & Val.
31. *Aprion virescens* Cuv. & Val.
32. *Pristipomoides filamentosus* Cuv. & Val.
33. *P. microdon* Steindachner
34. *P. microlepis* Bleeker
35. *Macolor macolor* Cuv. & Val.
36. *M. macularis* Fowler
37. *M. niger* Forskål

6. Pomadasidae (46 species) Grunts

1. *Caesio caerulaureus* Lacépède; *dalagang-bukid; lapas*
2. *C. chrysozonus* Cuv. & Val.; *dalagang-bukid*
3. *C. cuning* Bloch; *dalagang-bukid; lapas*
4. *C. digramma* Bleeker
5. *C. lunaris* Cuv. & Val.; *dalagang-bukid*
6. *C. pisang* Bleeker
7. *C. xanthonotus* Bleeker; *bilason; molong*
8. *Plectorhinchus albovittatus* Rüppell
9. *P. chaetodonoides* Lacépède
10. *P. diagrammus* Linnaeus
11. *P. faetela* Forskål; *kiting*
12. *P. goldmanni* Bleeker; *pasinko*
13. *P. lineatus* Linnaeus
14. *P. nigrus* Cuv. & Val.
15. *P. orientalis* Bloch
16. *P. pictus* Thunberg; *labian; gollabao*
17. *P. polytaenia* Bleeker
18. *P. schotaf* Forskål
19. *Pomadasys argenteus* Forskål
20. *P. grunniens* Bloch & Schneider
21. *P. guoraca* Cuv. & Val.
22. *P. hasta* Bloch; *agoot; icuran*
23. *P. maculatus* Bloch; *sikov*
24. *P. opercularis* Playfair
25. *P. therapon* Bleeker
26. *Scolopsis bimaculatus* Rüppell; *tagisang lawin*
27. *S. bilineatus* Bloch
28. *S. cancellatus* Cuv. & Val.
29. *S. ciliatus* Lacépède
30. *S. longulus* Richardson
31. *S. margaritifer* Cuv. & Val.
32. *S. monogramma* Cuv. & Val.
33. *S. personatus* Cuv. & Val.
34. *S. phaeops* Bennett
35. *S. taeniopterus* Cuv. & Val.; *tagisang lawin*
36. *S. temporalis* Cuv. & Val.
37. *S. trilineatus* Kner
38. *S. vosmeri* Bloch
39. *S. xenochrous* Günther
40. *Hapalogenys meyenii* Peters
41. *Pinjalo typus* Bleeker; *dalagang-bukid*
42. *Heterognathodon nemurus* Bleeker
43. *Gymnocaesio argenteus* Bloch
44. *Pterocaesio tile* Cuvier
45. *Mirolabrichthys tuka* Herre
46. *Luzonichthys waitei* Fowler

7. Ariidae (10 species) Catfishes

1. *Arius crossocheilus* Bleeker
2. *A. disper* Herre
3. *A. goniaspis* Bleeker
4. *A. leiotetocephalus* Bleeker; *buñguan*
5. *A. maculatus* Thunberg
6. *A. magatensis* Herre
7. *A. manillensis* Cuv. & Val.; *kanduli*
8. *A. thallassinus* Rüppell; *tabomomo; kanduli*
9. *A. venosus* Cuv. & Val.
10. *Hemipimelodus manillensis* Cuv. & Val.

8. Exocoetidae (11 species) Flying fishes

1. *Cypselurus altipennis* Cuv. & Val.
2. *C. atrisignis* Jenkins
3. *C. bahiensis* Ranzani
4. *C. caudimaculatus* Fowler
5. *C. nigripennis* Cuv. & Val.
6. *C. oligolepis* Bleeker; *isdang lawin*
7. *C. opisthopus* Bleeker
8. *C. poecilopterus* Cuv. & Val.
9. *C. simus* Cuv. & Val.
10. *C. spilopterus* Cuv. & Val.
11. *Parexocoetus brachypterus* Richardson

9. Sciaenida (8 species) Croakers

1. *Sciaena dussumieri* Cuv. & Val.; *ibot; kabang*
2. *S. russelli* Kuhl & Van Hasselt; *belake; kabang*
3. *Johnius belengerii* Cuv. & Val.; *ibot*
4. *Pseudosciaena anea* Bloch; *alakaak*
5. *P. axillaris* Cuv. & Val.
6. *P. diacantha* Lacépède
7. *P. sina* Cuv. & Val.
8. *P. goldmanni* Bleeker

10. Hepatidae (37 species) Surgeon fishes

1. *Hepatus achilles* Shaw
2. *H. bariene* Lesson; *indañgan*
3. *H. bleekeri* Günther; *labahita*
4. *H. elongatus* Lacépède
5. *H. fuliginosus* Lesson
6. *H. glaucopareius* Bloch & Schneider
7. *H. grammoptilus* Richardson
8. *H. guttatus* Bloch & Schneider (Richardson)
9. *H. leucopareius* Jenkins
10. *H. leucosternon* Bennett
11. *H. lineatus* Linnaeus
12. *H. lineolatus* Cuv. & Val.
13. *H. maculiceps* Ahl
14. *H. marginatus* Cuv. & Val.
15. *H. mindorensis* Herre
16. *H. nigricens* (Linnaeus)
17. *H. nigrofuscus* Forskål
18. *H. olivaceus* Bloch & Schneider; *indañgan*
19. *H. philippinus* Herre
20. *H. pyroferus* (Kittlitz)
21. *H. triostegus* Linnaeus
22. *Naso annulatus* Quoy & Gaimard
23. *N. brachycentron* Cuv. & Val.; *tudlo-an*
24. *N. brevirostris* Cuv. & Val.
25. *N. eoume* Lesson
26. *N. genimarginatus* Herre
27. *N. hexacanthus* Bleeker
28. *N. lituratus* Bloch & Schneider
29. *N. tapeionosoma* Bleeker
30. *N. thynnoides* Cuv. & Val.
31. *N. tuberosus* Lacépède
32. *N. unicornis* Forskål; *bakwak; tudlo-an*
33. *N. vomer* Klunzinger
34. *Zebrasoma flavescens* Bennett; *catol-catol*
35. *Z. veliferum* Bloch
36. *Paracanthurus theuthis* (Lacépède); *umayi*
37. *Ctenochaetus strigosus* Bennett

11. Amphacanthidae (22 species)

1. *Amphacanthus albopunctatus* Temminck and Schlegel
2. *A. canaliculatus* (Mungo Park)
3. *A. concatenatus* Cuv. & Val.
4. *A. corallinus* Cuv. & Val.
5. *A. doliatus* Cuv. & Val.
6. *A. fuscescens* Cuv. & Val.
7. *A. hexagonatus* Bleeker
8. *A. javus* (Linnaeus); *samaral*
9. *A. lineatus* Cuv. & Val.
10. *A. luridus* Rüppell
11. *A. oramin* Bloch & Schneider
12. *A. puellus* Schlegel
13. *A. punctatissimus* (Fowler & Bean)
14. *A. rostratus* Cuv. & Val.
15. *A. spinus* (Linnaeus)
16. *A. striolatus* Günther
17. *A. sutor* Cuv. & Val.
18. *A. tetrazonus* Bleeker
19. *A. vermiculatus* Cuv. & Val.
20. *A. virgatus* Cuv. & Val.
21. *Lo unimaculatus* Evermann & Seale
22. *Lo vulpinus* (Schlegel & Müller)

12. Labridae (14 species) Wrass-fishes

1. *Choerodon anchorago* Bloch; *banquilan*
2. *C. margaritiferus* Fowler & Bean
3. *C. melanostigma* Fowler & Bean
4. *C. oligacanthus* Bleeker; *lammon*
5. *C. schoenleinii* (Cuv. & Val.)
6. *C. zamboangae* (Seale & Bean)
7. *Xiphocheilus quadrimaculatus* Günther
8. *Pseudodax moluccanus* Cuv. & Val.
9. *Lepideplois albotaeniatus* Cuv. & Val.
10. *L. bilunulatus* Lacépède
11. *L. diana* Lacépède
12. *L. hirsutus* Lacépède
13. *L. mesothorax* Bloch & Schneider
14. *Wetmorella philippina* Fowler & Bean

13. Scaridae (39 species)
    1. *Scarus balinensis* Bleeker
    2. *S. bataviensis* Bleeker
    3. *S. bicolor* Rüppell
    4. *S. blochii* Cuv. & Val.
    5. *S. caudofasciatus* Günther
    6. *S. cyanognathus* Bleeker
    7. *S. dimidatus* Bleeker
    8. *S. dubius* Bennett
    9. *S. dussumieri* Cuv. & Val.
    10. *S. erythrodon* Cuv. & Val.
    11. *S. fasciatus* Cuv. & Val.
    12. *S. forsteri* Cuv. & Val.
    13. *S. frenatus* Lacépède
    14. *S. guttatus* Bloch & Schneider
    15. *S. harid* Forskål
    16. *S. hypselopterus* Bleeker
    17. *S. janthochir* Bleeker
    18. *S. kelloggi* (Jordan & Seale)
    19. *S. lineolabiatus* Fowler & Bean
    20. *S. margaritus* Cartier
    21. *S. microcheilos* Bleeker
    22. *S. microrhinus* Bleeker
    23. *S. muricatus* Cuv. & Val.
    24. *S. mutabilis* Gray
    25. *S. nuchipunctatus* Cuv. & Val.
    26. *S. oxedema* Snyder
    27. *S. oktodon* Bleeker
    28. *S. ophthalmistius* Herre
    29. *S. pectoralis* Cuv. & Val.
    30. *S. pulchellus* Rüppell
    31. *S. quoyi* Cuv. & Val.
    32. *S. rhodopterus* Bleeker
    33. *S. rubroviolaceus* Bleeker
    34. *S. schlegeli* Bleeker
    35. *S. tricolor* Bleeker
    36. *S. sordidus* Forskål
    37. *S. vermiculatus* (Fowler & Bean)
    38. *S. viridibusius* (Fowler & Bean)
    39. *S. visayanus* Herre

14. Ariidae (10 species) Catfishes
    1. *Arius crossocheilus* Bleeker
    2. *A. dispar* Herre
    3. *A. goniaspis* Bleeker
    4. *A. leiotetocephalus* Bleeker; *buñguan*
    5. *A. maculatus* Thunberg
    6. *A. magatensis* Herre
    7. *A. manillensis* Cuv. & Val.; *kanduli*
    8. *A. thalassinus* Rüppell; *tabomomo; kanduli*
    9. *A. venosus* Cuv. & Val.
    10. *Hemipimelodus manillensis* Cuv. & Val.

APPENDIX B

IMPORTANT PHILIPPINE FISHES HABITUATED TO LONG-RANGE LATITUDINAL MIGRATIONS

1. Engraulidae (12 species) Anchovies
    1. *Stolephorus commersonii* Lacépède; *dilis; bolinao; monamon*
    2. *S. indicus* Van Hasselt; *dilis; tuakang*
    3. *S. tri* Bleeker
    4. *S. heterolobus* Rüppell
    5. *S. japonicus* Houttuyn
    6. *Engraulis valenciennesi* Bleeker
    7. *E. dussumieri* (Cuv. and Val.); *dumpilas*
    8. *Thrissocles setirostris* Broussonet
    9. *Thrissina baelama* Forskål; *dumpilas*
    10. *Scutengraulis hamiltoni* Gray; *dumpilas*
    11. *S. mystax* Schneider
    12. *S. kammalensis* Bleeker

2. Clupeidae (18 species) Herrings
    1. *Ilisha ditchoa* Cuv. & Val.
    2. *I. hoevenii* Bleeker; *tuabac; dilat*
    3. *Sardinella leiogaster* Cuv. & Val.
    4. *S. clupeoides* Bleeker
    5. *S. sirm* Rüppell
    6. *S. brachysoma* Bleeker
    7. *S. melanura* Cuv. & Val.
    8. *S. perforata* Cantor; *lapad; halobaybay*
    9. *S. fimbriata* Cuv. & Val.; *tunsoy; laolao*
    10. *S. longiceps* Bleeker; *tamban; tuloy*
    11. *S. schrammi* Bleeker
    12. *S. jussieu* Lacépède
    13. *S. samarensis* Roxas; *tamban; lirayan*
    14. *Alosa platygaster* Günther
    15. *Harengula dispilonotus* Bleeker
    16. *H. tawilis* Herre; *tawilis*
    17. *H. moluccensis* Bleeker; *tunsoy*
    18. *Clupeoides lile* Cuv. & Val.; *silag*

3. Dussumierridae (5 species) Round herrings
    1. *Dussumieria acuta* Cuv. & Val.; *tulis*
    2. *D. hasseltii* Bleeker
    3. *Spratelloides gracilis* Temminck & Schlegel
    4. *S. delicatulus* Bennett
    5. *Etrumeus albulina* Fowler

4. Thunnidae (6 species) Tunnies, bonitos, yellowfins, albacores

1. *Auxis thazard* Lacépède; *tuliñgan*
2. *Grammatorcynus bicarinatus* Quoy & Gaimard
3. *Euthynnus yaito* Kishinouye; *bonito; katchot*
4. *Germo alalunga* Gmelin
5. *Katsuwonus pelamis* Linnaeus; *gallasan*
6. *Neothunnus macropterus* Schlegel; *tambacol*

5. Scombridae (9 species) Mackerels

1. *Scomber japonicus* Houttouyn; *lumahan; ababañgon*
2. *Cybium commerson* Lacépède; *tanguinge; tanigui*
3. *C. konam* Bleeker
4. *Acanthocybium forbesi* Seale
5. *Nesogrammus piersoni* Evermann and Seale
6. *Rastrelliger brachysomus* Bleeker; *hasa-hasa; aguma-a; masangui*
7. *R. chrysozonus* Rüppell; *alumahan; lumahan*
8. *R. canagurta* Cuvier
9. *R. loo* Cuv. & Val.

6. Sphyraenidae (7 species) Barracudas

1. *Sphyraena aureoflammea* Seale; *mangaijo*
2. *S. brachygnathus* Bleeker
3. *S. forsteri* Cuv. & Val.; *pangsalaon*
4. *S. jello* Cuv. & Val.; *asogon; torsillo*
5. *S. langsar* Bleeker; *bañgasan*
6. *S. obtusata* Cuv. & Val.; *babayo; torsillo*
7. *S. picuda* Bloch & Schneider; *rompecandado*

7. Carangidae (45 species) Cavallas, pompanos, etc.

1. *Trachinotus baillonii* Lacépède; *bitilla*
2. *T. blochi* Lacépède
3. *Caranx altissimus* Jordan & Seale
4. *C. armatus* Forskål; *buensang-sapse*
5. *C. auroguttatus* Cuv. & Val.
6. *C. butuanensis* Seale
7. *C. carangus* Bloch
8. *C. compressus* Day
9. *C. deani* Jordan & Seale; *talakitok & kalobe*
10. *C. djedaba* Forskål; *salay-salay; lalake*
11. *C. ferdau* Forskål
12. *C. fulvoguttatus* Forskål
13. *C. halli* Evermann & Seale; *pampanon*
14. *C. helvolus* Schneider
15. *C. ignobilis* Forskål; *lison; maliputo*
16. *C. kalla* Cuv. & Val.; *salay-salay aso; gela-gela*
17. *C. leptolepis* Cuv. & Val.; *habagat; lambiao*
18. *C. malabaricus* Bloch & Schneider
19. *C. malam* Bleeker
20. *C. manilensis* nom. nov.; *talakitok*
21. *C. mate* Cuv. & Val.
22. *C. melampygus* Cuv. & Val.
23. *C. oblongus* Cuv. & Val.
24. *C. opthalmotaenia* Bleeker; *talakitok*
25. *C. praeustus* Bennett; *salay-salay*
26. *C. sexfasciatus* Quoy & Gaimard; *muslo; simbad; pinkit; inggatan*
27. *C. speciosus* Forskål; *garapeche; talakitok*
28. *C. stellatus* Eydoux & Souleyet; *talakitok*
29. *Scomberoides lysan* Forskål; *dorado; talapia*
30. *S. sanctipetri* Cuv. & Val.
31. *S. toloo* Cuv. & Val.; *pipicao*
32. *S. toloo-parah* Rüppell; *cassisung*
33. *Alectis ciliaris* Bloch
34. *A. indica* Rüppell; *damis lawin; mangapahan*
35. *Seriola dumerili* Risso; *lumasang*
36. *S. nigrofasciata* Rüppell
37. *Hynnis momsa* Herre; *damis*
38. *Elagatis bipinnulatus* Quoy & Gaimard
39. *Selar boops* Cuv. & Val.; *atoloy; hasa-hasa*
40. *S. crumenopththalmus* Bloch; *matang-baca*
41. *Decapterus macrosomus* Bleeker; *galongong*
42. *D. russelli* Rüppell
43. *Megalaspis cordyla* Linnaeus; *oriles; uriles; bacutut*
44. *Eleria tala* Cuv. & Val.; *cassisung*
45. *Ulua mandibularis* Macleay

THE FISHERIES RESEARCH PROGRAM OF THE FISHERIES RESEARCH BOARD OF CANADA ON THE PACIFIC COAST

By W. A. Clemens

The Pacific Biological Station was established in 1908 for the purpose of enabling the Biological Board of Canada (now the Fisheries Research Board of Canada) "to conduct investigations of practical and economic problems connected with marine and fresh-water fisheries, flora and fauna, and such other work as might be assigned to it by the Minister of Marine and Fisheries."

It is natural that, in the development of this objective, emphasis should be given to systematic and natural history studies. In the early years, therefore, much attention was given to compiling lists of the rich fauna and flora of the Strait of Georgia area and life-history studies of certain fishes, particularly salmon and herring. Later there followed researches in biochemistry, in general physical and chemical oceanography, and in embryology and morphology to a limited extent. In recent years the work of the Station has been concerned with problems more directly connected with the commercial fisheries and efforts have been concentrated in the field of fishery biology, the life histories of commercially important shellfish, fish diseases, and dynamic oceanography.

The present discussion deals only with the more recent investigations, and, in view of the international character of Congress, reference will be made only to certain phases of the program which may be of general interest and application.

Studies of sockeye salmon propagation.—During the years 1925 to 1936 a study of the relative efficiencies of the natural and artificial propagation of sockeye salmon (*Oncorhynchus nerka*) was made by Dr. R. E. Foerster of the staff of the Pacific Biological Station, at Cultus Lake, tributary to the Fraser River. The efficiencies were computed on the relation of the number of seaward migrants to the total number of eggs contained in the females of each spawning escapement. The test of artificial propagation involved procedures such as are carried out by the most experienced and proficient hatchery officers using the most approved methods of the hatchery service.

In three tests of natural propagation the percentages were 1.13, 1.05, and 3.16, or an average of 1.78; in three tests of artificial propagation with liberation of free-swimming fry, 3.93, 2.38, and 1.71, or an average of 2.67; based on the actual number of fry liberated, the efficiencies were 5.83, 3.86, and 2.81, or an average of 4.16; in two tests of artificial propagation with the planting of eyed eggs, 0.95 and 3.57, or an average of 2.26.

The conclusions from these results which may be of general interest or application are (1) that the differences among the results from the three methods are not significant, and (2) that the mortality of 95 per cent between the time of liberation of the fry and the migration of the yearlings indicates that severe losses occur subsequent to hatching and therefore the destructive factors must act similarly on the products of all three methods of propagation.

With these facts at hand, consideration was given to the possible factors responsible for the 95-per cent mortality, and among the agents which seemed likely to be of most importance were paucity of food, diseases, and predators. Plankton studies at Cultus Lake had not revealed a lack of plankton crustacea, and when the number of seaward migrants had ranged from 43,447 to over 2,600,000 with no correlation between number of fish produced and efficiencies, the food supply did not seem to be the most important factor in limiting production.

Nothing is known concerning the occurrence of diseases among the fish in the lake.

The presence of considerable numbers of predators in Cultus Lake was known from observation. As the effect of their removal could be determinated directly on the basis of the percentage production of yearlings, it was decided to remove as many as possible of the predators such as squawfish (*Ptychocheilus oregonensis*), char (*Salvelinus malma*), trout (*Salmo gairdneri*) and coho (*Oncorhynchus kisutch*), and of such coarse fish as suckers (*Catostomus macrocheilus*), chub (*Mylocheilus caurinus*), and shiners (*Richardsonius balteatus*). Definite evidence of the effect of removal of over 13,000 predators during three years of operations would appear to be shown by a percentage production of yearlings of 13.6 from the liberation of 12,000,000 fry. It will be recalled that prior to the removal of predators production following fry liberation ranged from 2.81 to 5.83 per cent, with the average of 4.16. There would seem to be reasonable grounds for believing that the threefold increase in production is attributable to the destruction of the predator fishes. These quantitative studies of the production of sockeye salmon should provide a sound basis for additional investigations on the natural propagation of salmon and other fishes in other countries.

Salmon migrations.—Studies of the migrations in the sea of the various species of Pacific salmon have yielded information of value in the international field. Tagging programs involving all five species were carried out from 1925 to 1931, inclusive. Spring salmon (*Oncorhynchus tschawytscha*) tagged off the west coast of Vancouver Island showed a southeastward movement to the Fraser and Columbia rivers as well as to various streams along the Washington, Oregon, and California coasts. The majority of the tags were returned from the Columbia and two were taken in the Sacramento River. Tagging off the Queen Charlotte Islands also showed a southeastward migration with higher percentages of tag returns from Canadian waters. The tagging of sockeye salmon at the entrance to Portland Canal gave a high percentage of returns from the mouth of the Nass River, but a considerable percentage (20 per cent) were from Alaskan waters, some from as far as 105 miles from the point of tagging.

With each species there are areas where international boundaries are crossed and detailed information concerning the movements of the fish will make possible intelligent coöperation in conservation measures.

Pilchards.—Usually during July, August, and September schools of pilchards (*Sardinops caerulea*) appear off the west coast of Vancouver Island and support an extensive fishery. A program of investigation has been carried forward since 1929 by Dr. J. L. Hart, who has been concerned chiefly with the questions of the origin, abundance, and composition of the stock as it appears each year. Critical morphological examination of pilchards captured off the California and British Columbia coasts failed to show any constant differences. In recent years a coöperative tagging program among the states of California, Oregon, and Washington, and Canada has been undertaken and it has been found that a considerable number of British Columbia tags have been recovered in California reduction plants and an even larger number of California tags have been obtained in the various Canadian reduction plants. There is therefore no question of the interchange of pilchards as between British Columbia and California waters. The study of length distributions has failed to show the presence of definite age groups in any year, but the variations in average lengths from year to year have tended to indicate the passage of dominant year groups through the fishery.

It would seem fairly well established now that the pilchards off the west coast of Vancouver Island form part of the very large body of fish having its center of abundance off the coast of California. Each year a portion of the California stock of older fish tends to move northwestward, and usually, but not always, some fish reach the feeding grounds off the British Columbia coast and with the change in oceanographic conditions in the early autumn move southeastward to join the main body of fish in California waters.

Japanese oyster.—The seed of the oyster (*Ostrea gigas*) from Japan was first distributed in British Columbia in 1914. Since that time rather large quantities have been imported and a considerable industry has developed.

The seed arrives from Japan in February and March on shells of abalone, scallop, and oyster. It varies from 1/16 in. to 3/4 in. in length and makes rapid growth after distribution. Under favorable conditions the majority will mature the following year and spawn when 2 to 3 inches in length. Many are marketable at 2½ years of age, but usually they are marketed at 3 years.

Natural spawning to a greater or less degree has occurred with fair regularity. Dr. C. R. Elsey was able to induce extensive spawning by bringing about early maturity of batches of oysters and then distributing the sex products over the beds.

Successful spatting, on the other hand, has been exceptional. During the summers of 1932 and 1936 very extensive sets occurred in Ladysmith Harbor, but in other years since 1929 spatting has been negligible in amount. In 1938 Professor Ferris Neave conducted some experiments with the larvae and found that the larvae showed most vigor and growth when reared at temperatures of about 27° to 28° C. Such temperatures are rarely if ever attained in Ladysmith Harbor. Published data concerning the propagation of the species in Japan suggest that this oyster in Ladysmith Harbor is existing on the borderline of its temperature range and somewhat below the optimum temperature for early development.

It is possible that the occasional spatting of the Japanese oyster in British Columbia waters may be sufficient to maintain the industry, but it is likely that importations of seed from time to time may be necessary.

Oceanographic investigations.—One other phase in the program of fishery investigations may be mentioned, namely, the study of ocean conditions. Reference has been made to the movements of salmon and pilchards and to the propagation of the Japanese oyster. To understand the migrations of many species of fish as well as the distribution, reproduction, and growth of the fish, shell fish, and in fact of all the life of the sea, it is necessary to know something of the current systems, the distribution and cyclic changes in temperatures, salinities, and other physicochemical conditions.

To this end, the Station has carried forward a steady though somewhat limited program. An investigation of the Strait of Georgia by Dr. A. H. Hutchinson, of the University of British Columbia, disclosed the distribution of the Fraser River water and its relation to the prevailing high temperatures in the upper waters during the summer months. Temperatures of 20° C. and higher result from the fact that the fresh water spreads out over the surface, maintaining a stratum of low density accumulating solar heat and gradually distributing this heat to the general body of Strait water as mixing is brought about by winds and tidal flows. An account of the ultimate distribution of the Fraser River water and of the conditions prevailing in the Strait of Juan de Fuca is under preparation by Mr. J. P. Tully.

In addition, Mr. Tully has made a special study of the ocean conditions off the west coast of Vancouver Island, particularly off the entrance to the Strait of Juan de Fuca.

The factors of heavy land drainage, winds, tides, upwelling, and so forth, tend to create a rather complicated situation but one in which may be recognized five rather distinct seasonal conditions. Briefly, the outflow of large amounts of fresh water from the sounds and inlets tends to move northwestward along the coast. Owing to winds and reaction against the shore, the current turns seaward. As a result, a series of large vortices is formed which cause upwelling of the deep water. The sum of the series of vortices constitutes a northwestward current along the shore and a southeastward flow offshore.

These brief reviews of selected investigations may serve to indicate the character of the Board's research program, the aim of which has been to provide a body of fundamental information for use in the regulation, conservation, and development of the fishery resources of the Canadian Pacific coast.

ROLE OF THE BUREAU OF FISHERIES IN CONSERVATION

By Elmer Higgins

Introduction

The student of fisheries has long regarded the North Atlantic as the center of world activity in harvesting the resources of the sea. Exploitation of the Atlantic fisheries on a relatively large scale began perhaps a thousand years ago and has continued with increasing intensity from the shallower, near-by grounds to the more distant waters. This early development of the Atlantic fisheries was facilitated by the natural abundance of the fish supply, by the vast extent of relatively shallow water, by the pattern of ocean currents that favor maintenance of large stocks of fish, and by the relative accessibility of these productive areas. As a result of these centuries of exploitation the fishery resources, particularly those most accessible to the European nations, may now be regarded as having reached the maximum production possible under present economic and technological conditions.

Development of the Pacific fisheries.—During recent years, dominance in world fishery trade has been shifting rapidly to the North Pacific. This area now produces 17,062,000,000 pounds of fishery products as compared with 11,858,000,000 pounds from the North Atlantic. It is entirely possible that continued exploitation of relatively little utilized species may still further swell this total.

The more recent development of the Pacific fisheries may be explained in part by retarded technological development. The Industrial Revolution is still occurring in the fishing industry of the Pacific. The days of the sailing junk and sampan, the outrigger canoe, the umiak, the whale boat, and the dory as implements of capture in the Pacific are numbered. The internal combustion engine, artificial refrigeration, the vacuum sealing machine, rapid transport, and even the factory ship are transforming the fisheries of the Pacific from the stage of handicraft into modern big business operating on the basis of mass production.

Development of conservation ideals.—With this development of modern methods of exploiting the fishery resources has come, also, a gradual change in our ideas regarding the economy of the sea. The doctrine of inexhaustibility so widely held in Europe until the beginning of the present century has grudgingly lost ground and is slowly being replaced throughout the world by more complete understanding not only of the extent of the fishery resources but also of the factors that are responsible for their maintenance. Since the time of Theodore Roosevelt there has developed in America the realization of the need of conserving natural resources. The fishery operators themselves in the eastern Pacific are becoming more acutely aware of the need of restraint in harvesting products of the sea—of the need of exploiting these natural resources on the basis of sustained yield to provide maximum economic return in the present and also to assure future production.

Such a realization has been achieved none too soon. Already we have seen evidence of the devastating effect of unrestrained exploitation. Already we have witnessed the decline of important fisheries and the threat of their economic extinction. Fortunately, I can add that already we are witnessing the practical results of a system of conservation as applied to the fisheries.

Causes and cures of depletion.—Fishery biologists have long realized that overfishing produces varying degrees of depletion by simply removing the fish stock more rapidly than Nature can replace it. They have proposed various criteria for recognizing the early stages of depletion by observing changes in the character of the fish population itself. Detailed studies have demonstrated that when the strain of fishing falls primarily upon the mature individuals of the stock the average age of the population is depressed and the relative number of young or immature individuals, which usually are of less economic value than mature specimens, is increased. Such a phenomenon combined with a persistent decline in yield per unit of effort is accepted as a reliable indication of depletion.

Conservationists the world over have sought to forestall threatened depletion by various means, but seldom has a direct attack been made through simple regulation of the total catch. Ordinarily, practical considerations prevent such a simple treatment. Recourse has been had, therefore, to a variety of expedients in the form of legislation to limit fishing seasons, prescribe closed areas, fix size limits, restrict the amounts or character of fishing gear, and the like. All these impose handicaps or restraints on the fishing industry and many have unhappy economic effects because they prevent the development of the most efficient methods of operation and therefore increase the cost of production. Such restraints have often failed to aid in the conservation of the supply because they were based on faulty knowledge or were negligently applied. The increased economic burden which depresses fishing activity has too often been passed on to the consumer and thus the requirements of true conservation have not been fulfilled.

Only a single shining example of the direct attack upon the conservation problem comes to mind. This is the system of controls applied by the International Fisheries Commission established by the United States and Canada for the protection of the North Pacific halibut. Operating with ample legal authority, the Commission has regulated this fishery so that its total drain is balanced by the reproductive forces of Nature with a little to spare. The halibut fishery is perhaps the only high seas fishery that is being restored to something near its former productivity.

Some principles of conservation.—It has long been held, and indeed the conclusion is logically inescapable, that an adequate spawning reserve must be maintained if fishing is to be permanently productive. But what is an "adequate" spawning reserve? We find that determination of this quality is something that ever shifts and eludes us, because what may be adequate under certain conditions may be totally inadequate under a different set of conditions. The existence of few spawners does not always mean few young; nor does an abundant stock of adults necessarily insure adequate reproduction.

It may be useful to consider two classes of fisheries with respect to the utility of protecting a spawning reserve—a group in which the population is relatively stable, and a second group in which great fluctuations in abundance occur combined with the dominance of year classes.

It is evident that the halibut—a long-lived, slow-growing fish—is a species that is subject to relatively slight variations in annual production. Apparently the dominance of year classes that has characterized such species as the herring is not a particularly important phenomenon in the replacement of halibut stocks, and hence the numbers required for reproduction can be more readily determined. It is undoubtedly possible to build up the spawning reserve to good effect by regulating the annual withdrawals by the commercial fisheries.

No such stability characterizes fisheries of the second group. The herring, the mackerel, and to a lesser extent the haddock are well known to be subject to wide variations in abundance and exhibit marked dominance of year classes. During the past few years we have witnessed the production, from a very small stock of spawners, of a tremendous year class of striped bass on the Atlantic Coast—so abundant, indeed, as to raise total production in the fishery to more than twice the maximum yield in the 80's. This forcibly suggests that in such fisheries the number of surviving young may be largely independent of the number of spawners. As for mackerel, research has demonstrated an astonishing rate of mortality among the young that in some years results in virtual failure of survival, while we know that in other years tremendous year classes are produced that dominate the fishery throughout the entire lifetime of the brood. If we should attempt to maintain a stabilized mackerel fishery on the basis of the prospective spawning reserve, that reserve would have to be almost infinitely large during years of high mortality and correspondingly small when survival is notably successful. With respect to such species the significance of a spawning reserve fades in importance, and for wise utilization we must seek other principles than the time-honored one of protecting the spawning stock. If conservation means wise use, emphasis should be placed upon efficient utilization of such species at the point where additions to the total weight of a year class by individual growth are overbalanced by mortality.

Functions of the Bureau of Fisheries

These same theoretical considerations contrasted in the natural history of the Pacific halibut and the Atlantic mackerel apply with equal force to other fisheries in the Pacific, and subsequent research must determine to which category the important species belong. It is my purpose in this discussion to present an account of the responsibilities, functions, and research activities of the Bureau of Fisheries based on these principles with special reference to the Pacific rather than to discuss the principles themselves at greater length.

General functions.—The primary functions of the Bureau of Fisheries are largely investigational and advisory to the states. Formed by a joint resolution of Congress in 1871, the United States Commission of Fish and Fisheries, as it was then known, was charged with the duty of determining what diminution in the fish supply of our coastal waters, streams, and lakes had occurred, of discovering what caused the decline, and of recommending remedial measures. Biological investigation was, therefore, the first duty of the Bureau. In addition, the collection of statistics of commercial fisheries was undertaken at an early date and in more recent years has been amplified with a view to supplying practical aid to the fishing industry. In recognition of the need for making effective some of its recommendations regarding the maintenance of the supply, the Bureau was granted authority to undertake the artificial propagation of fish, and the hatching and planting of food and game fishes soon became the most extensive branch of the service.

Twenty years ago, in addition to investigational and fish cultural activities the Bureau was authorized by law to exercise control over the salmon and other fishes of Alaska, to regulate and supervise the Alaska fur seals and all fur-bearing animals of the Territory, to exercise control over the sponge fishery off the Florida coast, and to act as adviser to the states regarding fisheries legislation. Since that time various additions to the Bureau's duties have been made. For example, in 1920 the protection of walruses and sea lions in Alaska was transferred to the Secretary of Commerce and the regulation of fur-bearing animals in Alaska was transferred to the Secretary of Agriculture. In 1922 the Bureau was authorized to conduct rescue of fishes from flooded areas throughout the Mississippi Valley and to propagate mussels. In 1924 it was given administrative control over fishery matters in the upper Mississippi wildlife and fish refuge. The authority of the Bureau of Fisheries in Alaska was extended at the same time to permit complete regulation of the fisheries. In 1930 enforcement of the Federal black bass law was entrusted to the Bureau. In 1935 the Bureau was charged with the administration of the act authorizing the formation of coöperative associations of fish producers, and in 1936 the Secretary of Commerce was given power to issue regulations jointly with the Secretary of the Treasury governing the whale fishing under the international whaling treaty.

Now, on July 1, 1939, the entire organization of the Bureau of Fisheries and the authority exercised by the Secretary of Commerce with respect to fisheries has been transferred by executive order to the Secretary and the Department of the Interior.

Legal jurisdiction.—The Federal Government of the United States through its Bureau of Fisheries has no jurisdiction whatever over the fisheries within the territorial waters of the United States, for under the Constitution the Federal Government exercises only such powers as are specifically delegated to it or are reasonably derived from those delegated powers. Following the precedent of English common law, ownership of the fishery resources and therefore responsibility for their administration remains with the individual state governments as an attribute of sovereignty acquired upon separation of the Colonies from the Mother Country. Only in Alaska, which is a Territory, and in other Territories or Possessions of the United States has the Congress authority to legislate for the fisheries. Under the Commerce and Maritime clauses of the Constitution, however, the Congress has authority to regulate interstate and foreign commerce and to order the activities of American citizens on the high seas. This latter authority apparently has been exercised only once, however, when for a period of five years Federal laws were in effect regulating the mackerel fishery on the high seas off the Atlantic coast. The Federal Government also has full constitutional authority under its treatymaking power for the regulation of fishing jointly with nations signatory to any international agreement. This power, as you know, has several times been exercised with respect to fisheries, particularly in connection with the protection of the fur seals of the Pribilof Islands, the halibut of the North Pacific, and most recently the international salmon fisheries of the Fraser River and Puget Sound.

A question has sometimes been raised regarding the practical and even the legal justification for the Bureau of Fisheries' conducting fishery investigations in the offshore waters beyond the territorial limits of the United States. Granted that it is desirable from a purely scientific standpoint to acquire a knowledge of these natural resources, the question is asked, What can be done toward maintaining them, and if nothing can be done why should public funds be spent in such directions? An answer to such a question is that even if control of high seas fisheries were impossible, a knowledge of changes in abundance of fish supplies and a forecast of future events that may halve or double the fishery harvest has a very significant and practical value. No one argues that the work of a national weather bureau is useless even though, as Mark Twain says, we can do nothing about the weather but talk about it. But further than that, the contention is sound that men can do a great deal about the fisheries. It is technically possible so to reduce the supply of fish as to destroy its economic value, but it is equally possible to correct these mistakes, to maintain the supply once threatened, and even to restore it. I maintain, also, that it is possible under existing constitutional limitations to apply to a declining fishery such remedies as are discovered through technical researches. Within territorial waters the states now have complete authority. That authority may be extended and made more perfect through the device of the interstate compact by which groups of states each vitally interested in a commercial fishery in inshore waters can provide uniform or coördinated regulations that can be effective. On the high seas the Federal Government can impose a system of regulation for its own benefit where the interests of other nations do not interfere. Where a fishery is exploited by more than one nation, interests may be pooled by international agreement and regulations applied that meet all the requirements of conservation. That these types of control seldom have been applied in the past is no argument against material extension in these directions in the future. The trend is apparent.

Bureau's Research Program

The concern of the Bureau for the fisheries of the eastern Pacific is directed primarily toward the conservation of three of the most important fisheries in our inshore and near-by offshore waters—the Pacific salmons, the herring, and the pilchard. I shall discuss salmon conservation at some length because of the Bureau's responsibility for the salmon fisheries in Alaska and because the principles have wide application elsewhere.

Salmon investigations in Alaska.—The system of conservation of salmon is intricate and involved, but is directed primarily toward the maintenance of an adequate spawning reserve, for, with respect to anadromous fishes, this principle is readily applied. In 1924 Congress passed a law requiring the Bureau of Fisheries to protect 50 per cent of the total annual runs returning from the sea to our Alaska rivers for spawning purposes. At the time the law was passed, little information was available about mortality rates in the various river systems, or about the desirable size of the spawning reserve. It was realized, however, that important runs of salmon were suffering from excessive fishing and that if abuses and wasteful fishing should be allowed to continue an important resource would be doomed. It was thought that reserving 50 per cent of the annual runs of spawning fish would give Nature an even chance to maintain the resource. This law in general has been beneficial.

Only rarely, however, has the 50-per cent law been applied directly. Counting weirs have been established in 17 out of the hundreds of salmon spawning streams in Alaska, and efforts have been made by lengthening or shortening weekly closed seasons to balance the count of fish passing weirs against the numbers taken by the commercial fishery from those particular populations. In some few places where the commercial fisheries draw upon the runs headed for a particular spawning stream, such as the Karluk River on Kodiak Island, this effort has been very successful. In other places, where migration routes of the salmon pass through commercial fishing areas to a number of streams, the 50-per cent requirement for a spawning escapement cannot be applied with any great precision. Before regulation of the fisheries could in actual fact produce the intended effect, it has been necessary to conduct extensive tagging experiments to determine migration routes from fishing grounds to spawning areas, to discover the seasons or times when certain populations pass through a fishing area, and to chart the distribution of these runs in the various spawning streams.

In addition to tagging, similarly extensive marking experiments have been undertaken in which migrating fingerling salmon in lots of 50,000 or more at a time have been marked by the excision of a combination of fins. On returning as adults, these fish may be identified when taken in the commercial fishery and the contribution of the various independent colonies of salmon to the fishing areas more accurately estimated.

Where counting weirs cannot be established, either because of physical difficulties or financial limitations, a superficial type of stream survey has been conducted annually in Alaska streams at the end of the fishing season to estimate the numbers of spawning fish observed or the numbers of nests or redds established and thus to gauge roughly the spawning escapement.

To restrict the commercial catch within broad limits to the required 50 per cent, a great variety of fishing regulations have been established, including weekly closed periods when fishing is prohibited, limitation on the localities in which fixed fishing gear may be operated, spacing requirements to prevent the operation of too many units, closed areas where purse seining is prohibited, particularly in the vicinity of the mouths of spawning streams, and the adjustment of the beginning and ending of the open fishing season in the various districts, particularly in southeastern Alaska, to limit the drain of the fishery and to assure adequate escapement.

In order to gauge in advance the extent or the severity of fishery regulations that must be imposed to afford adequate protection and in order to be able to advise the salmon packers of Alaska sufficiently in advance to permit them to plan for future seasons' business, the Bureau's scientists have been endeavoring to forecast with considerable accuracy the expected runs of salmon in any major watershed. One of the foremost elements in such prediction is the normal ratio of the number of returning adult fish to the number of spawners in the parent escapement. This, of course, is the resultant of the combined survival rates of eggs, fry, seaward-migrating fingerlings, and ocean-dwelling adults. The ratio of return to escapement varies materially with different species and in different localities. Moreover, as might be expected, this ratio also varies from year to year for the same species in the same river. For example, the ratio of return to escapement for the red salmon in the Karluk River, Alaska, over a period of years has varied from as much as 5.6 to 1 to as little as 0.6 to 1; that is, the smallest spawning escapement yielded the largest percentage return of adult fish, while the largest escapement yielded the smallest percentage return.

To determine what return may be expected from any given escapement it is necessary to understand the causes of these large fluctuations in survival, but before this can be done the very considerable task of calculating the return from any particular spawning must be performed. This involves the age analysis of the entire run of fish to the river by examination of the scales of thousands of specimens taken in a systematic manner throughout the entire season, for the age of returning red salmon, for example, may vary from three to eight years. Recent studies have suggested a positive correlation between the growth of migrants during their stay in the lakes and the returns from escapements.

During a series of years overcrowding of the spawning grounds occurred at Karluk and dry weather undoubtedly restricted the spawning areas. These years were followed by very poor returns. Moreover, the average length of the seaward migrants was smaller than in years of more successful return, indicating that environmental conditions again, which affect the growth of young salmon, also affect their survival. Further studies of the environment of the young red salmon revealed that a seasonal deficiency of silicon and phosphorous has been occurring in recent years in the surface waters of Karluk Lake, with a corresponding decrease in the abundance of plankton food of young salmon.

Combined with these observations evidence has been adduced showing that in recent years the ratio of return to escapement has been consistently falling. At the same time the average age of the seaward migrants has been on the increase. This again indicates a shortage in the food supply which may explain the delay in starting seaward migration, during which period predators or adverse conditions in the lake continue to take their toll of the future runs before they reach the sea. A constant escapement of 50 per cent of the entire runs apparently is not enough to maintain the resource. Can it be that the lake is being impoverished of its nutrient materials through constant withdrawal by the commercial fishery of too great a number of salmon which by their dead bodies fertilize these waters and thus assure abundant food supplies?

The little-known life of the salmon in the sea has for years been regarded as having slight significance in any system of conservation. It has been held that if only fish enough were allowed to spawn, the industry could be conducted on a stabilized basis. Recent studies of the pink salmon in southeastern Alaska, however, throw a slightly different light on the subject. For many years it has been a matter of common knowledge that the time of migration in the major portion of the runs varies considerably from year to year. A detailed study of former yields indicates that a cyclic factor is involved, producing later and later runs by year, and then runs appear earlier in the season for a time. Late runs are composed of a considerable number of fish, but these fish are of smaller average size; whereas the early runs come from a small total population composed of fish of larger size. The hypothesis has been advanced, which unfortunately must still be regarded as speculation, that food competition in the sea occasioned by large populations reduces the rate of growth and sexual maturity is reached later in the season year by year as the population increases. When fishing reduces the runs the fish find sufficient food in the sea for their reduced numbers to make a rapid growth, achieve maturity, and appear as mature fish earlier in the season. To understand this phenomenon extensive researches in oceanography obviously are required.

A similar phenomenon has been observed in the red salmon runs of Bristol Bay, Alaska, although here circumstances considerably alter the details. In Bristol Bay the average age of returning adults varies considerably from year to year. In some years the 4-year-old fish predominate, in others the 5, and in others even the 6-year-old fish are most numerous. Unlike the pink salmon, however, which uniformly lives a 2-year life cycle, the red salmon lives 7 or 8 years and it may be that if food supplies in the sea are insufficient to produce mature fish in four years, perhaps the same fish can wait over and spawn in the fifth year, the sixth, or even the seventh. We may then speculate further as to whether or not feeding conditions in the sea have real significance in a system of conservation, for obviously, unless we know in advance the relative numbers of each year class that may be expected in an annual run, the total size of the run can only be guessed and proper provision for protection of a reduced run will be impossible.

Just a year ago, Congress made funds available to the Bureau of Fisheries for an attack upon this problem in Bristol Bay and a large-scale investigation is now well under way in that vast area. With the assistance of the Coast Guard an extensive program of oceanographic observations is being conducted, together with biological observations to discover the schooling habits of the fish far offshore, the food conditions that are found there, and the times and routes of migration from these offshore feeding grounds. Correlated with these ocean studies are investigations of the more conventional type relating to the life cycle of the salmon in the five major watersheds of this area. Detailed population studies will be made on the spawning runs, surveys of the spawning areas will be conducted, the success of reproduction observed, and the mortality of the young carefully determined. Because of the great commercial importance of the red salmon fisheries in Bristol Bay these studies will have corresponding values.

Although such an investigation was initiated as the immediate result of the threatened exploitation of the offshore salmon fisheries out near the edge of the continental shelf and thus beyond control by existing regulations, the objective is not to find additional fishing grounds, for the salmon supplies of Bristol Bay can be more economically exploited in the inshore waters, but to learn more of the factors that control the salmon populations in order to apply a sound and comprehensive system of management.

Salmon investigations in the states.—The same principles and the same objectives form the foundation of salmon-fishery investigations in the United States proper. Here, however, the states of Oregon, Washington, and California assume the burden of administration of the commercial fisheries and the Bureau's work is largely advisory. In the Pacific Coast states the depletion of the salmon resources is not alone the result of commercial fishing, although in the Columbia River it has been estimated that the drain of the commercial fishery takes four times as many fish as those that escape the nets and proceed to the spawning grounds.

In the states a factor of greatest importance in threatening the future supply is the man-made barriers and hazards erected in the rivers—the hydroelectric and navigation dams that obstruct free access of the adult fish to the spawning grounds, and the irrigation diversions that offer broad highways to destruction among the fields for the downstream migrants. On this account the efforts toward conservation have taken a direction slightly different from that in Alaska, where primitive conditions still obtain. Investigation has been directed toward discovering these hazards to natural propagation and devising effective means of removing or overcoming them.

Service functions in relation to salmon.—While not strictly a research function, the active measures taken as a result of our extensive field surveys in the Columbia River and our studies of fishways and ladders in coöperation with the War Department have been directed very largely by our scientific personnel. The success of the fishways in passing adult salmon over the Bonneville Dam has now been thoroughly demonstrated by the successful migration of nearly a half-million fish during the past year. The state of Washington and the Bureau of Fisheries have constructed more than 200 screens of a type that successfully prevents the downstream migrating fingerlings from entering irrigation diversions. During the present season we are faced with the necessity of conducting on a grand scale a biological experiment in the complete transplantation of a major run of salmon from the Columbia River obstructed by the Grand Coulee Dam to the major tributaries below the obstruction and establishing therein permanent runs of fish that will find even more extensive spawning grounds and perhaps even improved conditions of survival than the ancestral ones in British Columbia. Artificial propagation will play its part in maintaining the supply in the Columbia River, but here again better methods must be employed and new problems must be solved if we are to improve on natural propagation. This opens up a field of research that is relatively untouched.

Similar problems will be encountered on the tributaries of the Columbia River in Oregon and Idaho, and almost identical ones are facing us in the Sacramento River and its tributaries in California as a result of the extensive program of dam construction and impoundment. What our practical success will be is problematical, but we are facing the technical aspects of the problem with confidence.

Herring research.—Space and time will not permit an extended discussion of the problems of conservation of the herring and the pilchard, nor of the Bureau's program of investigations. The herring, although widely distributed around the northern coast line of the Pacific Ocean, presents in the eastern Pacific at least only local problems of conservation. I say they are local because research by Bureau investigators in recent years has demonstrated the existence of local stocks or races inhabiting relatively confined areas instead of a single homogenous stock throughout its range, and therefore since each unit of population is subject to overfishing locally the problems of control are of a restricted nature.

The history of the fishery in Alaska, where the greatest yields are obtained, has been one of intensive exploitation and rapid diminution of the supply area by area with the shift of activities from more intensively fished areas to those more recently exploited. The Bureau's conservation program, therefore, consists of careful analysis, year by year, of the age composition of the stock, of the extent of spawning activity, and of varying rates of survival which give rise to dominant year classes in different localities. It also involves the promulgation and enforcement of fishery regulations designed to limit the drain of the commercial fishery area by area when danger signs are detected, in order to increase potential production by spreading the harvest from a single abundant year class over a period of years rather than squandering it by unlimited fishing during a short period of time.

Although I cannot describe the details, I must comment upon the excellence of the careful scientific work that has been done on the biometrics of the herring populations and the great ingenuity that has been displayed in perfecting techniques of study. Doubtless you have all heard of the successful application of the tagging method to the study of herring migrations and the development of a most ingenious mechanical device—the electronic tag detector—that has proved so effective in delineating the areas inhabited by each particular race, the migrations from spawning grounds to feeding areas, and the intensity of the commercial fishery.

The accuracy and dependability of the scientific observations on the state of the supply have been matched by the wisdom and fortitude of our administrative officers in applying necessary restrictions on fishing activity in the various districts of Alaska. While we are far from achieving a perfect system of management that will assure future supplies, progress in recent years has been so gratifying that we are hopeful of ultimate success.

Pilchard research.—Perhaps of interest to a wider range of people are the conservation problems presented by the Pacific pilchard fishery prosecuted by three nations of the eastern Pacific. During the past quarter-century the pilchard fishery has risen to first place in landings in this region, yielding the greatest production in our three Pacific coast states. So intensive has been the exploitation of this vast resource, particularly in California, that grave fears have been aroused regarding its future stability.

Scientific investigation of the pilchard, or California sardine as it is locally known, was first undertaken by the scientific staff of the California Division of Fish and Game in 1919. Well do I remember the circumstances of its initiation, for I played a modest part in this investigation myself. Largely to facilitate these studies, the California State Fisheries Laboratory, which has become an institution of international repute, was established and its work on the sardine has developed and expanded throughout the years up to the present, producing a valuable literature upon the natural history of the species and tracing in minute detail the statistics of industrial production.

The basic problem remaining for solution is this: What is the optimum level of catch below which the stock would go to waste through underutilization and above which it would become reduced to commercial unimportance through overexploitation?

Before this level can be determined, three questions must be answered. First, How much is the stock reduced by commercial fishing? Second, How has the relation of income to outgo in the stock changed during the growth of the fishery? And, third, How much does fishing in specific areas affect the stock in other areas?

Answering these questions necessitates the determination of abundance, age, reproductive success, and importance of intermigration. These necessities determined the program of the Bureau's investigations on the pilchard during the past year. In October, 1937, the United States Bureau of Fisheries joined with the Fish Commissions of California, Oregon, Washington, and British Columbia in these studies to assist in the coördination of their results and to investigate those features needed to supplement the findings of the other agencies. With funds regularly appropriated by the Congress for this work, investigations on this subject will continue until results of satisfying practical application are attained.

Although the responsibility for administration of this great source of wealth must fall largely upon the state of California, from which the major portion of the catch comes, it may be that federal legislation or even international agreement will be required for the complete protection and management of the supply.

Conclusion

I have sketched thus briefly the scientific and administrative rôle of the United States Bureau of Fisheries in the conservation of aquatic resources, particularly in the Pacific. I hope that this summary treatment has not misled you into a belief that most of the work has been done, nor that the many gratifying achievements in the field are the sole property of the Federal agency. It is true that the success of the protection and conservation of salmon fisheries and seal resources in Alaska are the result of the work of the Bureau's scientists and administrative officers, but in all the other fields the Bureau shares with the several states and with numerous scientific institutions that have coöperated in a gratifying manner. I am sure you will realize that I have been compelled to omit all reference to the brilliant individual achievements of scientists, engineers, administrators, and conservation leaders who throughout a half-century have won permanent niches in the hall of conservation fame.

With a growing spirit of coöperation and mutual understanding, locally, among the states, nationally, and internationally, we may look forward to greater achievements in conserving and wisely utilizing our natural resources in the Pacific in the future, and in this work the United States Bureau of Fisheries, within its proper sphere, will spare no effort and shirk no responsibility.

HISTORY OF FISHING TECHNOLOGY AND ITS FUTURE

By J. R. Manning

Fishery technology is much younger than the technology of the utilization of the products of other food industries, and yet fishing as an enterprise is one of the world's oldest of human activities. Fishery technology, as an applied science, may be said to have had its official birth little more than twenty years ago when the United States Bureau of Fisheries introduced into this country a method of brine freezing which had been successful in Scandinavia in connection with the freezing of fish. It is quite true that prior to that time there had been scattered efforts here and there on the part of chemists, engineers, and bacteriologists both in government and in industry in this country to apply scientific methods to the utilization and commerce in fishery products; but there was no scientific staff, of any consequence, specially organized for the purpose of conducting fishery technological studies. However, it was this one step in the application of modern methods of refrigeration which greatly stimulated technical advances in the various fishery industries of the United States. Technical improvements have been made and are still being made in the application to the fisheries of other general methods of food preservation such as drying, salting, canning, and smoking.

In the field of canning, much work has been done, especially on commercial methods, and many relatively large and highly developed commercial fish canning industries have grown up in the United States, particularly on the Pacific Coast. Recently, technologists of the Bureau of Fisheries have spent considerable time in the development of methods of home canning fishery products and much progress has been made in this field. Technological studies on the salting of fish have been devoted largely to improvements in the penetrating properties of the salt. Several years ago it was found that impurities in the salt had much influence on this factor.

The smoking of fish and other foods as a means of preservation is shrouded in the dim mists of antiquity. But, like many ancient accomplishments, it is an art rather than a science. Therefore, the use of smoke in preserving food has depended largely on the skill of the individual, consisting of a somewhat rule-of-thumb method rather than one of uniformity or one based on scientific control. Technologists of the United States Bureau of Fisheries developed recently a model smokehouse whereby temperature, humidity, volume of smoke, and other factors which may influence the finished product are under complete control. In this way it is possible to prepare a smoked product of high quality and uniformity. The details of this method should be of importance to all food industries.

Technical developments in the handling and preservation of fish have tended to concentrate centralized processing at certain strategic points. Likewise, centralized processing has greatly helped the byproducts industries by making available at one point waste materials in quantities sufficient to justify economic reduction. It is in the field of byproducts utilization that fishery technology has particularly distinguished itself. Everyone has heard of halibut-liver oil. Had it not been for the work of technical men, halibut livers would still be thrown away at sea, where it has been customary to eviscerate the halibut since the very origin of this industry. Similar studies on the vitamin potency of other fish oils and fish-liver oils have created new industries, supplying these products as sources of vitamins A and D for both human and animal nutrition. Thus, feed manufacturers, poultrymen, physicians, drug manufacturers, and public health authorities are interested in and have been benefited by the developments of fishery technology in this one field alone.

When it is realized how little was known on this subject ten years ago, it is quite evident that commercial developments have been most rapid in placing the results of technological research into practice. It is also most interesting to study the development and gradual economic rise of fish meal, first as an ingredient of fertilizers, and now as an unexcelled feed concentrate for farm animals.

The fisheries constitute a vast source of raw materials for the products of many industries, including the food, drug, paint and varnish, farming (both of animal and plant foods), soap, and many others. Among the industrial commodities derived from aquatic products are: acetone, agar, alginates, algin, alginic acid, ambergris, pearls, shells and shell products, buttons, salt products, caviar, fish skins and hides, marine leather, marine animal oils and meals, coral products, epinephrin, fertilizers, glue, pearl essence, insulin, protamine insulinate and other glandular products, iodine, tortoise shell and ivory, isinglass, eelgrass paper, rubber compounds, seal fur, spermaceti, sponges, and many others of a diversified nature and with a wide range of usefulness. Thus it will be seen that technological research in the fisheries covers a broad field which necessarily involves the sciences of chemistry, physics, engineering, bacteriology, pharmacology, and general technology toward the development of new processes and methods, the salvage of waste products, and toward the more complete utilization of the fishery harvest.

It has been known for a long time that marine products possess certain distinct and unusual nutritional properties. It has only been in recent years, however, that there has been available much scientific knowledge on the subject. There is now ample scientific evidence to show that fishery products, as a class, are an excellent source of highly digestible proteins, of vitamins, and of mineral constituents in quantity and variety. Seafoods are an exceptionally rich source of iodine, which is essential to the prevention and treatment of simple goiter. Oysters have been shown to be second only to calf's liver as a source of iron and copper, minerals necessary to the prevention and treatment of certain types of anemia. Fish are a good source of the essential amino acids required in building body proteins in man and animals. We have already discussed the unexcelled properties of certain fish oils and fish-liver oils as sources of vitamins A and D.

As the science of mineral nutrition has progressed in recent years, there has been an increasing demand for knowledge concerning the functions and physiological effects of these minerals in the human body. The need for establishing standards of tolerance for some minerals such as arsenic because of their widespread use in sprays for fruits and vegetables has created a demand for knowledge concerning the metabolism of these minerals as they naturally occur in organic combination in foods as compared with inorganic sources of them. In recent years, the United States Bureau of Fisheries has maintained an experimental laboratory where pharmacological and biochemical studies have been made of arsenic and fluorine as they naturally occur in organic combination in certain fish and shellfish as compared with these minerals from inorganic sources. In general, the results of these investigations have shown that these minerals, naturally occurring in organic combination in fishery products, are not stored in the body of the animal to the degree that such minerals from inorganic sources are stored. From a practical standpoint, there need be no fear of toxicity developing from the inclusion in the diet of fish and shellfish, because of their natural content, of such minerals as arsenic and fluorine. The experimental data did show, however, that the inclusion in the diet of inorganic sources of these minerals did produce toxicity.

The future of fishery technology appears quite promising. There is much yet to be done to aid the fishery industries in making the most complete economic use of their raw materials. The possibilities for the development of fishery byproducts appear particularly attractive. Few other food-processing industries find byproducts of such relative importance. A rough estimate will indicate that byproducts represent about 15 per cent of the total value of all fishery products. In some of the individual fishery industries, byproducts are of much greater relative value. Because of the perishability of fish, the trend in the industry is toward centralized processing, and this trend naturally will increase the relative importance of the byproducts of the industry. Centralized processing also means that greater attention will be given to the improvement of existing methods and the development of new methods of preservation. This trend also has brought about the need for more thorough studies in warehousing technology, involving such important factors as more knowledge concering the proper temperature and humidity for storing frozen fish, the proper conditions of handling and storage of such byproducts as fish meal and fish oil to eliminate the hazards of deterioration, decomposition, overheating, and the hazards of fire. Fishery technology in the future will be called upon to develop specialized products from the fisheries for use in the various food, feed, chemical, and drug industries. In the medicinal field there are prospects, as yet almost completely undeveloped, for the preparation of glandular products.

In conclusion, it should be reiterated and emphasized that fishery technology is comparatively new, even though fishing as a human enterprise is old, and the possibilities for expanding the utilization of the products of our fishery harvest, through technical research, are just becoming apparent as a vast, unexplored field.

THE RESEARCH PROGRAM OF THE SOUTH PACIFIC INVESTIGATIONS OF THE UNITED STATES BUREAU OF FISHERIES

By Oscar E. Sette

The South Pacific Investigations of the United States Bureau of Fisheries is devoted exclusively to a study of the pilchard. No species of the Western Hemisphere is of more widespread interest and importance. Millions of pounds of pilchards are canned or made into fish meal and oil every year from Mexico to Canada, and unrecorded quantities of young are caught from San Francisco to Mexico and carried hundreds of miles away to become bait for larger food and game fishes. The species has even greater uses; for besides being valuable commercially to man, pilchards are of immeasurable biological importance, serving as food to a great host of fish-eating animals that abound in the ocean—the bigger fishes, the mammals, and the birds. In fact, among the Pacific Coast's marine vertebrate animals the pilchard occupies one of the most significant of the key positions in the biological chain.

As a fish with an international distribution *par excellence*, the perpetuation of its supply is naturally an international problem. As a fishery with various local peculiarities along its entire range, its management is likewise a local problem as well as an interstate one. Its breadth of geographic interest does not appear from the catch records, for as yet relatively small quantities have been delivered north and south of California. Nevertheless, these quantities are increasing, and it is well established that the pilchard is a migratory fish, the catch at any one spot representing only a segment in the cycle of a passing population that has spent and will spend other phases of its life elsewhere. Passage of one part of the cycle in waters to the south, in Mexico, where important nursery grounds lie; and of another to the north, from Oregon to British Columbia, whither the old adults migrate, gives an international aspect to conservation of this species that cannot be seen by mere inspection of the relative importance of the various local fisheries. In view of these facts, a program of effective conservation of the pilchard can be devised only by coöperation between the research agencies of the several state and national governments; and indeed, coöperative research has been in effect for several years. During this period, biologists of the Fisheries Department of the Pacific Coast states, of British Columbia, and of the Bureau of Fisheries have met annually to exchange information gathered during the preceding year and to plan programs of study. These meetings serve to avoid overlap of work on the one hand and neglect of attention to important problems on the other.

Thanks to the painstaking studies made during the past eighteen years by the California State Fisheries Laboratory and by the Fishery Department of the Province of British Columbia, a great deal is now known about the pilchard. It has been established that it undergoes fluctuations in abundance, several dominant year classes having been traced through the fishery throughout their lives. It has been shown that the pilchard reproduces, for the most part, in southern waters, where the young are generally more abundant than elsewhere. In later life it migrates northward in summer and returns to southerly regions in time for the following spring spawning. Finally, considerable evidence has been deduced to indicate that the withdrawals by the fishery have reached such a magnitude as to produce a noticeable effect on the availability of the fish and on the size composition of the population. This observation, which I shall call the "exploitation effect," has yet to be translated from a qualitative to a quantitative basis. In other words, while it is known that there is an effect, we do not know how great it has been. And while a program of management is clearly indicated, it is yet to be determined how large an exploitation effect could be permitted under such management, how many tons of fish could be taken without impairing an abundance that is self-sustaining on a paying level.

Perhaps local limitation of the fishery, as recommended by the California State Fisheries Laboratory, that is, restriction of the catch to a certain annual total, can afford a means of accomplishing this end by measuring the reaction of the stock to various experimental fishing intensities. An experiment of this kind, however, must be carried on over a sufficiently great number of years to establish a trend; and this may mean a very long time indeed for a species that fluctuates as much as does the pilchard. This being true, it would be desirable, even urgent, that observational methods be devised for measuring the relation between recruitment and mortality losses. In other words, we should measure the size of the incoming year classes and the rate of their removal; and we must know the productivity of the adult population that is left for replenishment. From these data we should be able sooner to devise a permanent plan of management and more quickly stabilize the fishery.

Such observations are difficult, because pilchards are not randomly distributed through the water, but occur in schools and aggregations of schools. This fact has so far prevented measuring the required quantities; for the schools are selective with respect to size, and enter and leave the field of availability so as to offer the fishermen, in effect, a selection of selections. Then, too, the fishery itself is more or less selective, so that the commercial catch itself is a selection of the third order, which produces problems of sampling that are very perplexing indeed.

One of the principal tasks, therefore, is to devise techniques for solving these problems. Experiments in methods of representative sampling are being tried, utilizing data collected for this purpose, and also an extensive series of samples collected over an eighteen-year period by the California State Fisheries Laboratory and kindly put at our disposal by that organization. To further interpret these data, the Bureau is developing methods of determining age. It has been found that when the scales and also otoliths of young pilchards are properly prepared and examined, annual marks are more or less clearly evident, and are formed once a year during the fall and winter. It now appears perfectly feasible to determine the age of individuals up to at least the third year; and the work is being extended to learn whether the adults too may be aged by this method.

The Bureau is also experimenting with methods of studying the age composition of the samples by resolving multimodal frequency distributions into their component parts, using the before-mentioned eighteen-year series of samples. Likewise, new methods of interpreting the catch statistics are being developed. For this purpose, records for a group of boats fishing off Central California from 1931 to 1939 were made available by the offshore reduction plants and supplemented by the California Division of Fish and Game; and similar records were obtained from Washington and Oregon. This work is made possible largely because of the excellent fishery statistics collected by the Pacific States. Too frequently a lack of adequate statistics is a barrier to following the history of a fishery. In the present case, no such barrier exists.

When present difficulties in interpretation of data derived from the commercial fishery are overcome, there will remain the need of measuring the relation between replenishment and the spawning reserve. In anticipation of this need the Bureau has begun a quantitative study of the egg and larval stages. With equipment especially designed for quantitative sampling of the plankton, the Bureau undertook a survey of spawning and nursery grounds in the spring of 1939, and it plans to continue the work during subsequent years.

From this we expect to gain a knowledge of the abundance of spawn in the ocean and thus obtain a clue to the abundance of the spawning population. Then, too, fluctuations in the mortality of egg and larval stages, that is, survival, should indicate fluctuations in the success of the several year classes and should form a basis for predicting the success of commercial fishing perhaps by as much as three years. The relation of spawning to hydrographic and climatological phenomena is likewise being studied, temperatures and water samples being taken in connection with the plankton samples. Eventual precise determination of any correlation between success of spawning and some such environmental element as temperature, for example, might well simplify the task of measuring relative survival; for it is naturally much easier, quicker and cheaper to take temperatures or water samples than to haul plankton nets.

The work which I have briefly outlined has been undertaken by the Bureau of Fisheries as a useful service to the other organizations engaged in pilchard research. For them, the aim of their work is fishery management by local control. Should the international character of the fishery necessitate, however, a larger plan of management along the entire coast might be required. For such an eventuality, the information now being accumulated about the pilchard should well serve usefully in formulating such a plan.

THE WORK AND PROGRAM OF THE NATURAL HISTORY MUSEUM OF STANFORD UNIVERSITY IN FISHERIES AND GENERAL ICHTHYOLOGY

By George S. Myers

Introduction

Stanford University was first opened to students in 1891, under the presidency of Dr. David Starr Jordan, and since both he and Professor Charles Henry Gilbert, head of the Department of Zoölogy, were active ichthyologists, the University at once became an ichthyological center. At first nearly all the work was in systematics. After completion of the monumental *Fishes of North and Middle America*, Dr. Jordan initiated and carried out explorations and investigations of the fish faunas of Alaska, Mexico, Panama, Hawaii, Samoa, and Japan, the work being undertaken in conjunction with Professor Gilbert or various students.

Dr. Jordan's relationships with the federal Fish Commission (later the United States Bureau of Fisheries) had always been close, and he had conducted many fishery surveys for them. It was inevitable that the University should be drawn into fisheries work, and in his later years Professor Gilbert devoted most of his time to the study of the life history of the Pacific salmons. Professor J. O. Snyder, who had done excellent systematic work on Japanese and California fresh-water fishes, also took up investigation of salmonids of commercial or angling importance.

With this beginning, it was natural that systematic work on the fishes of all parts of the Pacific Basin should be continued, and also that work on species of economic importance should be carried on.

Reorganization of the School of Biological Sciences has placed ichthyological work at Stanford University in charge of the Natural History Museum, except for certain work on marine fishes carried on by Professor Rolf L. Bolin at the University's Hopkins Marine Station at Pacific Grove on Monterey Bay. The work resolves itself into three sections: systematics, fisheries, and teaching.

Systematics.—The work on the fundamental subject of fish classification is carried out on an extensive scale, especially since comparatively few institutions in the Pacific area concern themselves to any great extent with this subject. The Museum's fish collection, based upon the materials gathered by Dr. Jordan and his associates and students, is constantly growing, and is estimated to contain over 300,000 specimens. It is especially complete in the fishes of western North America, from Alaska to Panama, and contains what is probably the best existing representation of the shore and lowland fresh-water fishes of the area between central Japan and the southern Philippines, including the coast of China. It is also very rich in the fishes of Oceania, the East Indies and Malay Peninsula, Australia, Peru, and the Galápagos Islands. No other museum collection, save perhaps those in Washington and London, contains so complete a series of the fishes of the Pacific Basin. The ichthyological libraries in the Museum are also very complete.

The Museum staff has at present no regular program of ichthyological research on a particular Pacific area save for the long-continued researches of Dr. A. W. Herre, Curator of Fishes, on the fishes of the Indo-Pacific zoölogical region. In this fauna Dr. Herre's work has added enormously to our knowledge of the fishes of the Philippines, China, the Malay Peninsula, Borneo, Burma, and Oceania. In other work, especially that on the fishes of western North America, careful revisions of various systematic groups have been published or are in preparation. These studies are frequently undertaken on a wide scale, since sound systematic revisions, especially of marine species, can scarcely ever be delimited by political boundaries. It is hoped that revisions of this type will pave the way for a projected definitive monograph of the fishes of the eastern North Pacific, covering not only systematics but also summaries of existing knowledge of growth stages, life histories, and ecology. Work on the classification of the fresh-water fishes of the western states is also being carried on.

Fisheries work.—Most fisheries investigations of large scope can be undertaken only by governmental agencies, on account of expense and the long time periods involved. For this reason, the University has seldom or never undertaken problems of this type except in collaboration with the official fisheries agencies of the various states or of the federal government. Such collaboration may be either of two types. Certain problems, or partial or entire direction of them, may be placed, by the governmental agency concerned, in the hands of a qualified member of the academic staff, or minor problems may be taken over by certain advanced fisheries students who are partially or wholly supported by the agency wishing the investigation prosecuted. In investigations of either type, both the governmental agency and the student or professor charged with it derive benefit.

What has been said above will make clear why the Museum, as part of a private institution, has no distinctive fisheries program of its own. However, coöperative projects of the kind mentioned are, and will continue to be, carried on as opportunity offers. Professor Willis H. Rich, who is in charge of fisheries work at the Museum, has recently organized a Department of Research for the Fish Commission of Oregon, and holds the directorship of the department. Dr. Rich's research is concerned chiefly with the extremely important salmon resources of the Columbia River, now threatened by dams and other industrial developments. Professor F. W. Weymouth, of the Department of Physiology, who collaborates with Dr. Rich in the University's fisheries work, has recently been in charge of the shrimp investigations of the Bureau of Fisheries in the Gulf of Mexico, and various students are or have been working recently at various other fishery problems.

One method of coöperation which has been found very advantageous is the gift of laboratory and office space in the University to governmental fishery agencies. Several such fishery agencies have maintained headquarters at the University for many years. Until removed to a new building in Seattle a few years ago, the important United States Bureau of Fisheries' Alaska Salmon Investigation made its headquarters at the Museum. At the present time three fishery agencies are guests of the University. The federal Bureau of Fisheries' Pacific Pilchard Investigation is housed in Jordan Hall, and the Bureau of Fisheries' California Trout Investigation, and various offices of the California Division of Fish and Game are maintained in the Museum. These agencies derive benefit in the form of free laboratory and office quarters with excellent library facilities, in close proximity to their field of work, and the Museum staff and students are enabled to maintain close connection with active fishery research. The concentration of a large number of persons interested in all branches of ichthyology makes it possible to hold regular meetings at which actual problems are discussed, both formally and informally.

Teaching.—Since the Museum is a part of the School of Biological Sciences of Stanford University, it is a teaching as well as a research institution. Regular courses of studies are offered, which, in conjunction with work in the Department of Biology, may lead to the bachelor's, master's, or doctor's degree. Teaching is therefore perhaps the most important function of the Museum as now organized, and in view of the Museum's emphasis on ichthyology, the training of fisheries workers is given special attention. Naturally, the field of fishery research is not a very large one and good positions are not plentiful. For this reason, and because the Museum and its staff are not equipped to handle more than a few advanced students, no large number of students is encouraged to enter fisheries training. Moreover, no formal instruction in the actual technique of net handling, hatchery operation, artificial fertilization, bottom sampling, or even the handling of hydrographic gear, is given. Emphasis is laid on a broad biological background, an adequate knowledge of chemistry, physics, fish classification and habits, contact with fishery researchers, and participation in actual fishery investigations.* With this broad training, and the production of an adequate dissertation on the results of a research problem, it is felt that the student obtaining a doctorate in fisheries should be able to handle in a competent manner any fishery problem with which he is likely to be faced. The success of this type of training is reflected in the large number of Stanford graduates now holding positions of the highest importance in fisheries research, not only in the United States, but in other Pacific countries as well.

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* In fresh-water fishery problems, the student must be well grounded in land use, as well.

FISHERIES RESEARCH PROGRAM OF THE CALIFORNIA STATE FISHERIES LABORATORY

By W. L. Scofield

Under the state government of California, there is a Department of Natural Resources made up of five Divisions, Forests, Mining, Oil and Gas, State Parks, and Fish and Game. The Division of Fish and Game is composed of several Bureaus, one of which is the Bureau of Marine Fisheries, and the California State Fisheries Laboratory is the research department of this Bureau. Some of the investigative work with mollusks and anadromous fishes is supervised from our San Francisco office, but the work with marine fishes is directed from the Laboratory on Terminal Island at the harbor of Los Angeles in southern California. The work includes both the commercial and sport fisheries, as marine angling for recreation has grown to large proportions in this state. Enforcement of laws and regulations is handled by a separate body of specially trained marine wardens of the Division of Fish and Game, but management policy for the fisheries, regulations, and proposed legislation usually originate in the Bureau of Marine Fisheries and are guided by recommendations of the research laboratory.

Our research staff, including clerks, consists of twenty-five members. Our field work is augmented by the corps of thirty marine law enforcement officers, who carry most of the collection of fisheries statistics and are of very material assistance in recording general observations of operations in the fisheries. At Terminal Island we have two two-story buildings, one for biological investigations and the other housing our statistical work. An adequate library is a vital part of the headquarters laboratory. Staff members are frequently stationed at coastal cities, such as Monterey and San Francisco, where field work is conducted at the fish docks, on fishing vessels, and from our own research and patrol vessels. We operate one fully equipped 101-foot research vessel and utilize the services of an 85-foot patrol vessel. In addition, we are granted the use of one or more of six high-speed 45-foot patrol boats when need arises.

Our research program is designed to supply the information most needed for managing the state's fisheries on a basis of sustained yield. That means that first consideration is given to population studies. Measures of population and its changes are necessary and we attempt to distinguish between natural fluctuations in abundance and the changes caused by man's fishing. This involves estimating the survival from successive spawnings and, of course, complete records of the portion of the population harvested as annual catch. Such studies should answer the questions of whether or not the fishery is in need of protective regulation and the degree of overutilization, if it has occurred. Then comes the question of what kind of regulation promises to accomplish the purpose intended. At this point a knowledge of the behavior of the fish is necessary, so life-history studies are carried on to determine reproductive characteristics, growth rate, and migrations in order that we may recommend effective measures for protection where needed. With a knowledge of whether or not depletion is occurring and, if so, the degree of overutilization and what can be done to remedy the condition, the managers of a fishery are in a position to so regulate fishing operations that the crop harvested will about balance the average annual replacements, and may, theoretically at least, conduct the fishery on a sustained yield basis, harvesting the maximum continuous annual crop.

Such intensive studies require years of work and continuous observation to avoid possible depletion so long as the fishery continues. We therefore concentrate our efforts upon the most important fisheries, which are for the sardine, mackerel, tuna, flatfishes, and salmon. Less important fisheries receive more superficial examination in order that we may supply administrative officers and legislative committees with some knowledge to assist them in their management of these lesser fisheries. Incidentally, this more hastily gathered information frequently finds its greatest use in heading off useless or detrimental legislation.

Research results are published by the California Division of Fish and Game as *Fish Bulletins,* which are exchanged with organizations and mailed to fisheries workers; and more popular articles appear in the quarterly magazine, *California Fish and Game.* Occasional articles concerning fisheries appear in the monthly magazine, *California Conservationist,* published by the Department of Natural Resources.

Four of our important fisheries involve states other than California. Most of our tuna are caught off the coasts of Mexico and Central America. Sardines are fished from Mexico to British Columbia. Our mackerel fishery as yet has not extended into Mexican waters, but a considerable portion of the population may be spawned and reared south of our border. Salmon migrations are sufficient for something of common interest between California and Oregon. Of these four, the sardine and tuna have an international aspect and concern more than two administrative agencies.

So far as fisheries research is concerned, there have been most harmonious and mutually helpful relations between the various workers and their respective governmental departments. It may be that the results of investigations are recognized as beneficial to all agencies and that the purpose of research is to learn facts useful to the proper maintenance of the fisheries by whatever authority. The object is to benefit the fish rather than solely to enhance the organization doing the work. By contrast, management of fisheries is not so unselfish and there is a natural hesitation to enter into agreements that might be more beneficial to others than to the contracting party. The coöperation is not wholehearted until all parties are convinced that the benefits will be strictly mutual and that no one agency is striving to enhance its own prestige. Possibly it is for this reason that international coöperation has been limited and the relations between states and the various agencies of our own federal government have not been without suspicion and some aloofness. It would seem that coöperation comes about most easily when motives are pure.

PROGRAM OF THE INTERNATIONAL FISHERIES COMMISSION

By William F. Thompson

In presenting these remarks on the program of the International Fisheries Commission I wish to call your attention to the fact that Dr. Van Cleve has discussed the international aspects of the life history of the halibut in another section of the Congress. And may I also say that any program is dependent for its formulation and success on the staff who are responsible for it. To H. A. Dunlop, F. H. Bell, R. Van Cleve, J. L. Kask, W. C. Herrington, and the many others of the staff who have contributed, may I pay my sincere tribute for their successful research and for the years of utmost harmony and coöperation which have made it a great pleasure to be associated with the staff of the Halibut Commission.

The International Fisheries Commission, founded in 1925 by the convention between Canada and the United States for preservation and extension of the Pacific halibut fishery, has the inestimable advantage of a definite and yet comprehensive single objective placed on a basis of research, stated imperatively in a treaty between two great nations.

It is not made an administrative agency, told to enforce a variety of laws arrived at by the sometimes mysterious processes of popular opinion. On the contrary, it has been specifically charged with the duty of research as a basis for regulation.

Its objective in this research is not a multitude of unrelated problems. It is not faced with the dilemma of having to hold popular support by trying actually to answer this multitude of problems, each of which may really be of major character. It does not need to hope that the public will be satisfied with, or that it will forget to inquire into, the adequacy of a number of minor contributions that individually get almost nowhere. On the contrary, it can devote its energies to one species, it can give each phase of the life history or economics the importance it requires. Its sole hope of securing popular support is, and has been, the attainment of its objective, the rebuilding of the supply of halibut. This objective is simply and concretely stated, and the results are susceptible of being measured in definite ways. The Commission could not "run a bluff" for long; that is certain.

If the Commission has been bluntly and inescapably faced with a definite objective, it has been given the necessary freedom and scope of approach. As far as the species and fishery are concerned, there are left no internal administrative divisions. The whole unit is its responsibility and placed at its disposal. Along our coasts the two nations signatory to the treaty control the fishery completely, and the treaty unites these controls unreservedly.

This gives a freedom to the research which is remarkable. The undivided control encourages initiative aiming boldly at great objectives. The inevitable impulse to leave the job to the other fellow is absent. The hard thing must be, and is, faced, because there is no one else to blame its neglect upon. In many investigations there are frequently important and difficult problems in the background which cannot be attacked because the interests directly involved lack the magnitude necessary to justify the work. But in investigations by the Halibut Commission, if there is fundamental research to be done, the weight of the whole unified problem impels to an attack upon it. Thus, if a general problem as to the nature of migration arises, research upon it does not have to be justified by the need of some small section of the grounds, but by that of the whole of a great fishery. An expenditure of a thousand dollars on the study of growth shrinks to its true perspective, justified by the needs of two thousand miles of coast line, not by that of five hundred.

The man in the fleet and trade knows this. The work to be done is not to satisfy some local demand, thrown to the top by some exigency of politics. It is on a plane too high for that, and to the extent that it is, it commands widespread respect and support. Contact with the small political world is not one of its problems. There is no interference within the staff, because it is too small, the Commission too prominent, to justify the risk of bringing political pressure upon the staff or its conclusions. There is no imperative necessity to cater to selfish demands. The scientists of the Commission have high ideals and have been allowed to live up to them.

The conditions are as nearly ideal as they can be made. The result should be a program comprehensive in outlook and as well balanced as undisturbed judgment can make it. So far as the program has been successful, it demonstrates that it has been worth while to give scientific research the best of conditions under which to do its work. The success attained is a tribute to the members of the Commission, who have seen through the years that these conditions were preserved. The members have been Messrs. J. P. Babcock, W. A. Found, Miller Freeman, Henry O'Malley, E. W. Allen, T. T. Bell, L. W. Patmore, and A. J. Whitmore, the last-named four being the present incumbents.

I have often tried to put the program into the fewest words possible. It is a worthwhile thing to do because men who make appropriations, as well as those who include them in our budgets, want brevity and definiteness as well as practical purpose. It does not seem, for instance, that a long biological explanation of a project to determine the age of an organism does much more than confuse most nonscientific men, especially when it is stated vaguely that it is a necessary step in "investigating" the condition and needs of a fishery, which it is not in any immediate sense. A vague explanation with the weight of scientific authority behind it may silence, but it cannot convince.

Put into few words, the program of investigation has been to determine what unit of the stock of fish must be dealt with, and then to discover what must be done to that unit. There is an abundance of biology, of statistics, and of nearly every other science necessary to do those seemingly simple things. I need not detail each step in such biological or statistical research, as it is familiar to all of you. I can more profitably emphasize the conditions under which it is done, as they really determine the success.

To ascertain what unit must be dealt with is basic. With respect to the halibut it has meant the securing of answers to several large questions. First, what is the extent of the migration of the several stages of halibut life, as this decides the degree of independence of different sections of the banks? Second, what units can be defined for regulation in view of existing economic, political, and technological factors?

The migration of the halibut of commercial size has been dealt with by tagging on a large scale, and the resultant method of approach is worthy of study. Tagging which depends for results on the placing of tags in one section of a fishery extending over 2000 miles of coast, or which gives incomplete returns, or which is carried on and analyzed without regard for the relative chances of recovery in one direction or another from the point of tagging, can hardly be expected to give usable results. Tags placed on halibut at Yakutat shortly before the intensive fall fishery on the nearby "W" grounds must of necessity give heavy returns from the latter ground, emphasizing disproportionately those fish which may have moved a short distance. So also, tags placed just before the cessation of a fishery on a given bank can hardly give any idea of the number which fail to migrate, and the occasional distant migrant can only mislead. And again, if it is worth while to spend twice its commercial value to tag a fish, if vessels and men are employed to liberate marked fish, certainly every effort to recover them must be made. Large enough rewards, thorough publicity, and adequate staff to search for them, and a search with absolute impartiality and uniform method, must be included. All these needs, the Halibut Commission with its freedom to act and its wide outlook, has been capable of meeting. In fact, the work of tagging has been complete as possible in plan, thorough and unified in execution. And it has given what was expected of it—a picture of migration discounting the varying intensity of fishing and the seasonal shifting of the fleet. The picture is not made up of isolated, perhaps extraordinary, individual returns, but of considerable numbers that suffice to give reliable averages for comparison. It has taught us that half-hearted, poorly financed and poorly planned, partial experiments are not worth doing. They must be boldly planned, be on a large scale, and be decisively handled.

So, too, with early life-history migrations, such as egg and larval drifts. When the Commission began its work, the egg or larval stages had not been seen. To outfit a vessel, take it out with nets designed to filter all the water possible, regardless at first of niceties of measurement, and embark on a program of making hauls over a good share of the North Pacific, was, in a sense to court disaster. It was done as a venture, as research, and had halibut eggs not been taken it would have been considerable of a dud. Yet the staff felt no qualms in the adventure, and that is a tribute to the freedom which the Commission gave it. The fact that the search for halibut eggs and larvae was a great success and that it was done on a scale sufficient to show what was the natural unit for regulation, justified the venture; but had there been no such success, the venture could still have been justifiable as research, had it cost a hundred thousand dollars, because it was logical.

Finally, the unit suitable for regulation was defined by statistical studies. These too, were made on a sweeping, comprehensive scale that included the whole coast in a single research project. No collaboration of coöperating but independent research men could have succeeded. Only the same precise treatment of boats from Bering Sea to the coasts of Washington could give a graph of varying abundance that was comparable along our whole coast line; only such treatment could enable us to compare the rates of decline in abundance off Kodiak Island and off Vancouver Island. The attempt showed the great decline in abundance; it demonstrated that the stock westward of Cape Spencer had declined in a way that was different from that of the stock to the southward, a thing that could only have occurred in independent stocks. It corroborated the tagging and life-history studies in defining the units which were to be regulated separately. It showed the economic and technological differences between different parts of the fleet so that the separation of units could be done reasonably and without shock to the economic structure of the fleet.

The same freedom of thought and action that sanctioned these major projects and allowed them to be carried out decisively and boldly, led naturally to an ambitious attempt to answer the second question, What must be done to each unit as finally defined?

The attempt was nothing less than a reconstruction of what had happened, and was then happening, on the individual banks. First, the history of the banks for many years past was obtained from records collected from the whole fleet, and here again Canadian and United States, Alaskan and Puget Sound vessels, had to be dealt with alike. The mortality rates, of death and of fishing, were determined from tagging experiments. The growth rates were determined by studies of otoliths and scales. The intensity of the fishery as it modified the fishing rates was determined from our statistics. In the attempt almost every phase of our research played its part. Large tables were constructed, and a hypothetical stock of halibut was carried through year by year to its final decimation and disappearance. The work brought to light certain mathematical relationships that had in part been known from theory. The theoretical reconstructions matched the actual history of each section of the banks. The great accomplishment was undoubtedly the bringing together of concrete biological and statistical facts for the whole fishery in a manner adequate to answer a practical question with respect to what had happened to the halibut banks and what must be done to save them.

It showed that the prime factor in the decline was the overintensity of the fishery, and that the fishing must be restricted. It showed that a yield as large or larger would be obtained by a fleet half the size or less. It showed that the less intense fishing would allow the fish to live much longer and produce more spawn.

The fishery was restricted. The abundance doubled. The production of spawn increased. The fishery has not lost in poundage. The halibut are taken in half the time and with half the effort. They are landed in far better condition—so much better that the technologist can now handle them by improved methods and sell them in England in full competition with the best product of the Atlantic halibut fisheries, now badly depleted even on the last of the great banks, off Greenland.

The economic changes have been radical. Half the fishery meant half as long a season. Continued productivity of the banks has meant a larger fleet. To accommodate these changes, the fleet itself has organized a system of voluntary control, and in doing so has been encouraged by the Commission. Each vessel is limited in poundage per trip which it can take, and must tie up a certain length of time after each trip. Thus the season is prolonged. A system of self-control, extending across international borders, has been built to supplement the biological control of the Commission. The result is a most remarkable instance of a managed economy, extending, as it does, across state, provincial, and federal boundaries.

But the task is not done. The changes are not complete. The fishing fleet has been shown to be the key influence in determining the condition of the fishery. The fleet varies from year to year, and the result of its variations must be followed and guarded against.

Moreover, it is not yet known what the optimum conditions for productivity are. Has restoration gone even a fair fraction of the distance it can profitably go? How large a stock must be maintainad to produce a sufficient number of breeders? How many eggs must be produced? What happens as the species adapts itself to the greater abundance of fish? After the lessened intensity of the fishery has resulted in a larger stock of fish, will the decline in abundance be resumed? Many things are possible, and many great questions concerning the behavior of a population under the strain of varying mortalities are involved. They are questions that must be answered not only in the halibut, but in every great marine fishery. If they are answered in a practical way even in part, the result will stimulate marine research the world over. Surely small jealousies and selfish interests can be forgotten for such a goal.

Every practical consideration, every consideration of the scientific problems involved, calls for close observation, adequate in scope with proper background of knowledge. The statistical records, the examination of market catches to show changes in sizes taken, the measurement of abundance of eggs by plankton nets, must be continued. There may be needed even increased research activity and greater expenditures. It is possible that changes will have to be made in present methods of observation, or that they will be incorrectly interpreted. If this first really adequate and successful attempt at regulation of a deep-sea fishery is allowed to bog down into a rut, a major tragedy of present-day fisheries science will have been written. A great experiment is undertaken, full of hope for our great depleted sea fisheries the world over. Will it remain vital and progressive? Will it live or die?

It will live, if its program allows to the scientific staff the freedom of approach, the scope of accomplishment, that it has had in the past. It will live if research plans are adequately made, adequately carried out, and adequately financed. It will live if it continues to cover the whole fishery from Bering Sea to California with uniform research methods, uniform and impartial administration, and regulations based on fact, not on response to pressure; in short, if the regulation of the halibut remains what it has been, a unit based on wide-flung international research, its control and its research complete and unchallenged from without and within.

I have tried to show that the work of the Commission has been done under particularly favorable conditions. This seems to me to be a problem for the administrator as much as for the scientist. There is not much in the conditions which could not be duplicated in other staffs. But certainly they will not be unless the scientist himself believes in them and lets the administrator know that he needs them.

THE PRESENT STATE OF THE COLUMBIA RIVER SALMON RESOURCES

By Willis H. Rich

The salmon of the Columbia River have supported an intensive fishery for over seventy years but are now showing unmistakable signs of depletion, and various factors are contributing to the rapid progress of this condition. Five species of fish enter into the commercial fishery on the Columbia River itself. These are (1) the Chinook salmon (*Oncorhynchus tschawytscha*), (2) the blueback salmon (*O. nerka*), (3) the silver salmon (*O. kisutch*), (4) the chum salmon (*O. keta*) and (5) the steelhead trout (*Salmo gairdneri*). The Chinook is of far greater importance than all other species together and constitutes by weight approximately three-quarters of the total catch. In addition to the catch made in the river a large number of Columbia River salmon are taken in the ocean, especially by trolling, but to a small extent by purse seines. This oceanic catch is almost exclusively composed of Chinooks and silver salmon.

The annual commercial value of the pack of salmon on the Columbia River has averaged about four and a half million dollars over the past thirty years. Thousands of people are directly dependent upon this industry for all or part of their income and other thousands benefit indirectly. It constitutes one of the major resources of the Pacific Northwest.

Unfortunately there are no satisfactory statistics on the catch of Columbia River salmon. There are no records at all of the sort necessary to measure the fishing effort and only within the last few years have catch data been taken by the states of Oregon and Washington in such form that they can be combined to give reliable figures of the total catch. For past years a rough approximation of the catch is given by the pack figures published by the Pacific Fisherman and, more recently, by the United States Bureau of Fisheries (Fiedler). These are the best available data covering a long period; yet these are unreliable in a number of ways, of which the following may be mentioned: (1) The pack figures only give the packs of canned and mild cured salmon and do not include those sold fresh or processed in other ways. (2) There are included fish brought in from other streams, and Columbia River fish shipped elsewhere are excluded. (3) During various periods there has not been an accurate segregation of pack by species; Chinooks have been listed as of "chum grade" and steelheads have presumably been packed as Chinooks.

In spite of the imperfection of the data it is reasonably certain that they give a fairly good picture of the trend in the annual catch during the history of the fishery. Craig (1938) has given these data in their most acceptable and readily available form. (See also Oregon State Planning Board, 1938.) With certain corrections and modifications and supplemented by similar figures for 1937 and 1938, compiled from the Pacific Fisherman Yearbook for 1939, these data are presented in table 1. Here the figures are in the form of the average annual catch in pounds for each five-year period beginning with the years 1866 to 1870. There was no segregation by species previous to 1889, but an estimate has been made of the catch of Chinooks previous to this year on the assumption that the percentage of Chinooks in the total pack (which was the only record) was the same as for the period 1889 to 1910—approximately 80 per cent. A similar estimate was not made for the other species, because each represents such a small percentage of the total that such estimates would be exceedingly unreliable.

From this table it is apparent that the catch of Chinooks has consistently declined during the past twenty years and that during this period the average catch has been lower than for any other period except one (that ending with

TABLE 1

AVERAGE ANNUAL POUNDAGE OF COLUMBIA RIVER SALMON FOR FIVE-YEAR PERIODS, 1866 TO 1938, IN THOUSANDS OF POUNDS

Period	Chinooks	Bluebacks	Silvers	Chums	Steelhead
1866–1870	3,264	....	....	....	....
1875	14,348	....	....	....	....
1880	25,024	....	....	....	....
1885	31,493	....	....	....	....
1890	20,998	....	....	....	....
1895	24,248	2371	2986[b]	844[c]	3662
1900	23,257	1819	3330	988[d]	2104
1905	28,941[a]	784	1374[b]	1138[a]	604[a]
1910	23,282	723	2934	2154	624
1915	26,982	899	3472	3010	1899
1920	30,437	809	4519	3476	1980
1925	22,014	1198	6237	2077	2393
1930	20,326	725	5995	3975	2885
1935	18,192	299	4279	1158	1781
1936–1938	16,540	708	4044	2241	1720

Data from Craig, 1938, and Pacific Fisherman Yearbooks for 1938 and 1939. Up to and including 1888, the poundage of Chinooks has been estimated on the basis of 80 per cent of the total poundage as estimated from the figures of total pack given in Pacific Fisherman Yearbooks.

[a] Average of four years. There are no pack data for 1901.

[b] Average of four years. There are no data for 1891 or 1901.

[c] Figures for 1893 and 1895 only.

[d] Figures for 1899 and 1900 only.

1890) since the period ending with 1875. The catch of bluebacks has declined even more markedly, but much of this decline apparently took place rather suddenly about 1900. The trend of the catch of silvers and chums was upward from 1890 to about 1920. Since then, the catches of these species has fluctuated considerably and it is difficult to see any marked change. What change there is, however, appears to be in the direction of reduced catches. The catch of steelhead has remained fairly constant so far as the general trend is concerned. The most important species are the Chinook and bluebacks and it is apparent that these are the very ones that show most clearly a reduced abundance.

There are two main reasons for this depletion. First is the reduction in the area for spawning and rearing of the young fish that has come about through the advance of settlement and civilization along the tributaries where the salmon once spawned unhindered. This advance has meant, and still means, the erection of dams and other obstructions to the ascent of the spawning adults, the construction of irrigation ditches into which the young fish pass on their seaward migration, the imposition of other hazards to the seaward migrants, and the reduction of water flow in the natural stream channels, which effectively makes the areas available for the rearing of young salmon smaller and therefore less productive. This reduction in spawning and rearing area has been constant over a number of decades and has recently been accelerated by the initiation of a program by the federal government for the construction of numerous great dams that may well result in the extermination of a large part of the remaining runs of both Chinooks and bluebacks. Just what proportion of the original spawning and rearing areas remains is not known, but the survey now under way by the United States Bureau of Fisheries will eventually provide this important information.

But in addition to this, these fish have for many years been subjected to a very intensive fishery and without much protection other than what is afforded by artificial propagation. There is one closed period that covers the months of March and April, another the period from August 25 to September 10, and there are weekly closed periods of 24 hours during the open season from May 1 to August 25. This weekly closed period is practically useless so far as the escapement of fish through the commercial fishing area is concerned because the fish require from two to three weeks to cover this part of the river. Closure for one day a week, therefore, only benefits the fishermen above any given point. It extends, slightly, the productive fishing area, but without materially increasing the ultimate escapement at the upper limit of the commercial fishing region.

The two seasonal closed periods likewise do nothing for the runs of bluebacks, which are at present confined to the period between May 1 and August 25. They do, however, protect in some degree the runs of Chinook salmon that enter the river during March and April and during the August–September closed period. Since the Chinooks composing these protected runs may, by chance, enter the river either a little before or a little after the period covered by the parent run, the effect of this protection has been to hold up the catch during the time just preceding and following the closed periods. This effect is not so apparent preceding the spring closed period, because comparatively few Chinooks enter the Columbia during February and March, anyway.

The intensity with which the fishery within the river is carried on has been well brought out by a study made last year for the United States Bureau of Reclamation (Calkins, Durand, and Rich, 1939). On the basis of actual counts of fish passing Bonneville Dam and of estimates of the numbers taken in the commercial fishery, it was determined that during 1938 the ratio of catch to escapement for the bluebacks was over 3 to 1. For the Chinooks this ratio varied from approximately 3.5 to 1 during May to over 6 to 1 in June and July, but fell in August to about 1.5 to 1. Furthermore, for the Chinooks the fishing intensity was so great during June and July that, while the catch in the lower river was quite steadily increasing, there was no significant change in the number of fish passing the Bonneville Dam until late in July. The intensity is indicated also by the fact that, for most of the weeks during these two months, the catch in the lower river steadily declined from Monday until Saturday at such a rate that the catch at the end of the week was often less than half what it had been at the beginning of the week.

But this intensive fishery within the river is only part of the story. The troll fishery for salmon that extends from southeastern Alaska to Monterey Bay makes heavy inroads on the Columbia River Chinooks during their life in the ocean. It is impossible to determine with the data at present available the exact extent of this drain on the resource; but it can be shown to be a large element.

Experiments have been conducted by various agencies in which Chinooks captured in the troll fishery were tagged and released and data were later obtained concerning the place of recapture. These have shown that a large percentage of the fish captured by troll north of the Columbia River as far as southeastern Alaska were bound for the Columbia. Unfortunately there are no equivalent data on the troll fishery to the south of the Columbia River and it is not known how extensively, if at all, this draws upon the Columbia runs.

In southeastern Alaska such tagging experiments were conducted by the United States Bureau of Fisheries in 1926 and 1927. Out of a total of 470 Chinooks tagged there were 38 returns; 22 (58 per cent) were taken in the Columbia River (Fisheries Service Bull., 1928). The Biological Board of Canada carried on an excellent series of experiments for a number of years that covered the entire outer coast of British Columbia. In the north, around the Queen Charlotte Islands, 2117 Chinooks were tagged and 277 were captured, of which 27 per cent were taken in the Columbia River. Along the outer coast of Vancouver Island 3485 were tagged and 421 recaptured, of which 56.5 per cent had gone to the Columbia (Pritchard, 1934). There have been no similar determinations of the proportions of Columbia River Chinooks in the extensive trolling operations conducted in the region of Swiftsure Bank off the coast of Washington, nor in those conducted off the mouth of the Columbia itself; but it may fairly be assumed, I believe, that the percentage of Columbia River fish in the catch on Swiftsure Bank is not less than has been shown for the fishery along the west coast of Vancouver Island and that practically all the Chinooks taken off the mouth of the Columbia derive from the runs to that river.

Satisfactory statistics on the catch of Chinooks by troll in Alaska are not available. The various reports on Alaska fisheries and fur-seal industries (Bower, 1936, 1937, and 1938) give annually the weight of Chinooks taken by troll, but an unknown part of this catch is made in inside waters where, probably, the percentage of Columbia River fish is different from what was determined by the tagging experiments. The average weight for the whole of Alaska for the three years 1935 to 1937 inclusive was approximately 700,000 pounds. On the basis of the available information on the percentage of Columbia River fish taken in southeastern Alaska and northern British Columbia, it seems conservative to assume that at least 200,000 pounds of this catch may be attributed to the Columbia runs.

So far as I am aware, there are no published records of the poundage of Chinooks taken by troll in British Columbia. There is a rather large fishery there, however, and it is probable that the catch of Columbia River Chinooks considerably exceeds that made in Alaskan waters.

For the fishery along the Washington coast, especially in the region of Swiftsure Bank, Rounsefell and Kelez (1938) give the catch in terms of numbers of fish for the years 1927 to 1934. The average is nearly 200,000. The poundage is not given. Certainly half these fish can be considered to belong to the Columbia River runs.

Data on the troll catch off the mouth of the Columbia are given conveniently in a report on commercial fishing operations in the Columbia River by the Oregon State Planning Board (1938). Table 4 of that report gives the average annual catch for a ten-year period, 1928 to 1937 inclusive, as approximately 730,000 pounds, all of which may safely be ascribed to the Columbia River runs.

It is useless to attempt to put all these data into comparable form or to try to give more than a rough estimate of the number and poundage of Columbia River Chinook salmon that are taken in the troll fishery. It is certainly large, perhaps nearly 2,000,000 pounds, and since many of the fish are small the number caught may well reach 200,000 or more. It is greatly to be hoped that more satisfactory statistics will eventually be available.

This troll fishery has developed almost entirely since about 1915 and may well have had much to do with the reduced catches within the river itself that have been made since the five-year period ending with 1920. The catch of troll fish made off the mouth of the Columbia enters into the data given in table 1, so that, as this new fishery was developing, it was to be expected that the total catch would rise, as it did during the five-year period ending in 1920. After this initial rise, however, it was to be expected that the total take would fall as a result of the still further reduction of the breeding stock. This may well have been an important element in the conspicuously reduced productivity of recent years. In this connection it should be noted again that the number of fish taken by troll is much greater than would be required to make up the same poundage if the fish were taken in the river. Many of the troll-caught fish are immature and would not spawn for one or more years (Rich, 1925). During this time they would naturally remain at sea, where they would increase several times in weight. Also there are persistent rumors that the trollers kill many fish that they do not land because the fish are smaller than the buyers will ordinarily accept.

The way in which the Chinook salmon runs have held up under excessive exploitation and a constant reduction in the available spawning area is remarkable. I mentioned above that about the only protection given to the Columbia River salmon has been that afforded by artificial propagation. Biologists in general are skeptical of the claims made for artificial propagation, and rightly so because these claims have often been extravagant and the proof is entirely inadequate. Indeed, many conservationalists feel that the complacent confidence felt by fishermen, laymen, and administrators in the ability of artificial propagation to counterbalance any inroads that man may make upon the supply of a propagated species is a serious stumbling block in the way of the development of proper conservation programs. But it is to be noted that there is probably no salmon run of consequence that is so intensively propagated by artificial methods as is that of the Chinook salmon on the Columbia River. Even though satisfactory proof of the value of artificial propagation is lacking, it seems quite possible that there is a causal relationship that we do not understand between the intensive artificial propagation and the resistance to exploitation that the species has shown. This is a matter that, in my opinion, should have an important place in the study of salmon problems generally, and particularly in the study of those of the Columbia River. The possibilities of developing methods of artificial propagation that will produce satisfactory returns in terms of fish of commercial size is too great to be passed over lightly or with prejudice. But to be satisfactory the returns must be sufficiently in excess of those to be expected from natural propagation to warrant the expenditures incurred in operating the hatcheries.

We come, then, finally to this general picture of the present state of the salmon resources of the Columbia River. So far as our data show, the steelhead, silvers, and chums are nearly, if not quite, holding their own. The blueback runs were greatly reduced as long ago as 1900, since which time there has been no marked change in the size of the catch. This depletion of the bluebacks was probably due chiefly to the reduced spawning area available. The Chinook salmon catch has held up remarkably in spite of a fishery that is evidently being conducted with terrific and increasing intensity, but the record since 1920 is one of constantly decreasing catches. Reduction of breeding areas, which at present is accelerated, and an oceanic troll fishery that annually takes large numbers of both mature and immature fish, contribute to the environmental pressure against the species. Regulation of the fishery within the river protects only the runs of April and early May and those of late August and early September. In the face of this evidence the conclusion seems inevitable that the abundance of the Columbia River Chinook salmon will continue its present rapid decrease unless the species is given more adequate protection, either through regulation of the fisheries both in the ocean and in the river, or through enlarged and improved programs of artificial propagation.

The Columbia River salmon resources are, intrinsically at least, nearly if not quite as valuable as were those of the Fraser River before the destruction of the great sockeye salmon runs that appeared there quadrennially until the disaster of 1913. In the face of tremendous odds the Chinook salmon still survive in the Columbia although markedly depleted. The several opposed forces are diverse in character and it may be that they will eventually prevail; they will certainly do so unless concerted and intelligent effort is made to overcome them, and even that may not be enough. At present there is confusion and great need for an integrated conservation program. Since international cooperation is essential, it would seem that the federal governments of the United States and Canada should act together. There is already a functioning organization that could properly be entrusted with this responsibility—the International Pacific Salmon Commission, which was established by treaty for the purpose of rehabilitating the sockeye runs to the Fraser River. It is my suggestion that the proper steps be taken to provide that body with authority and funds adequate to extend its work to include the preservation of the Chinook salmon runs of the Columbia River.

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TEMPERATURE-CONTROLLED VARIATIONS IN THE RATE OF DEVELOPMENT OF PSETTICHTHYS MELANOSTICTUS, A PACIFIC FLOUNDER

By Richard T. Smith

Introduction

Psettichthys melanostictus is a species of flounder widely distributed in the coastal waters of the Pacific Ocean along the coast of northern North America. Its ova are pelagic and float freely about in the ocean currents carrying them. This discussion deals with the experimental hatching of these ova under controlled temperature conditions.

Acknowledgments

The author is indebted to Dr. W. F. Thompson and Dr. R. A. Van Cleve of the International Fisheries Commission for the use of the constant temperature equipment developed by the Commission for use in halibut research. The author was also accorded permission to retain the data collected during the experiments. Dr. T. G. Thompson of the Oceanographical Laboratories, University of Washington, kindly allowed the collection of supplies of sea water from the research vessel *Catalyst*. Several students of the School of Fisheries, University of Washington, aided in the experimental hatching through constant service in operating the machine.

Methods and Apparatus

The Commission has developed a constant temperature machine based upon the principle of a refrigeration plant. Thermostatically controlled temperatures are maintained in each of the six compartments of the machine. A bell jar in each compartment holds the water in which the eggs are hatched. Vertical stirring rods carrying disks create gentle currents which imitate those in which the ova would naturally develop. The developing ova were kept in constant motion in these currents, and were therefore pelagic throughout the hatching period. An almost complete water change was effected daily with the added water being passed through coils that brought it to the temperature of the tank to which it was added. Water of suitable density to give the ova neutral buoyancy was obtained through blending surface water collected at Richmond Beach, Washington, with water collected 500 feet below the surface of the Straits of Juan de Fuca off Clallam Bay, Washington.

TABLE 1

Time Consumed in Attaining the Various Stages of Development

Temperature of incubation	Stage A	Stage B	Stage C
deg. C.	*h.m.*	*h.m.*	*h.m.*
7.5	4:35	72:00	126:11
9.1	3:40	66:00	126:45[a]
10.8	3:36	54:08	97:28
12.0	3:35	48:37	80:44
14.7	2:21	37:49	68:25
16.8	2:19	34:47	60:02

[a] The ova incubated at this temperature became adhesive shortly before hatching and adhered in clusters, probably altering the time to hatching.

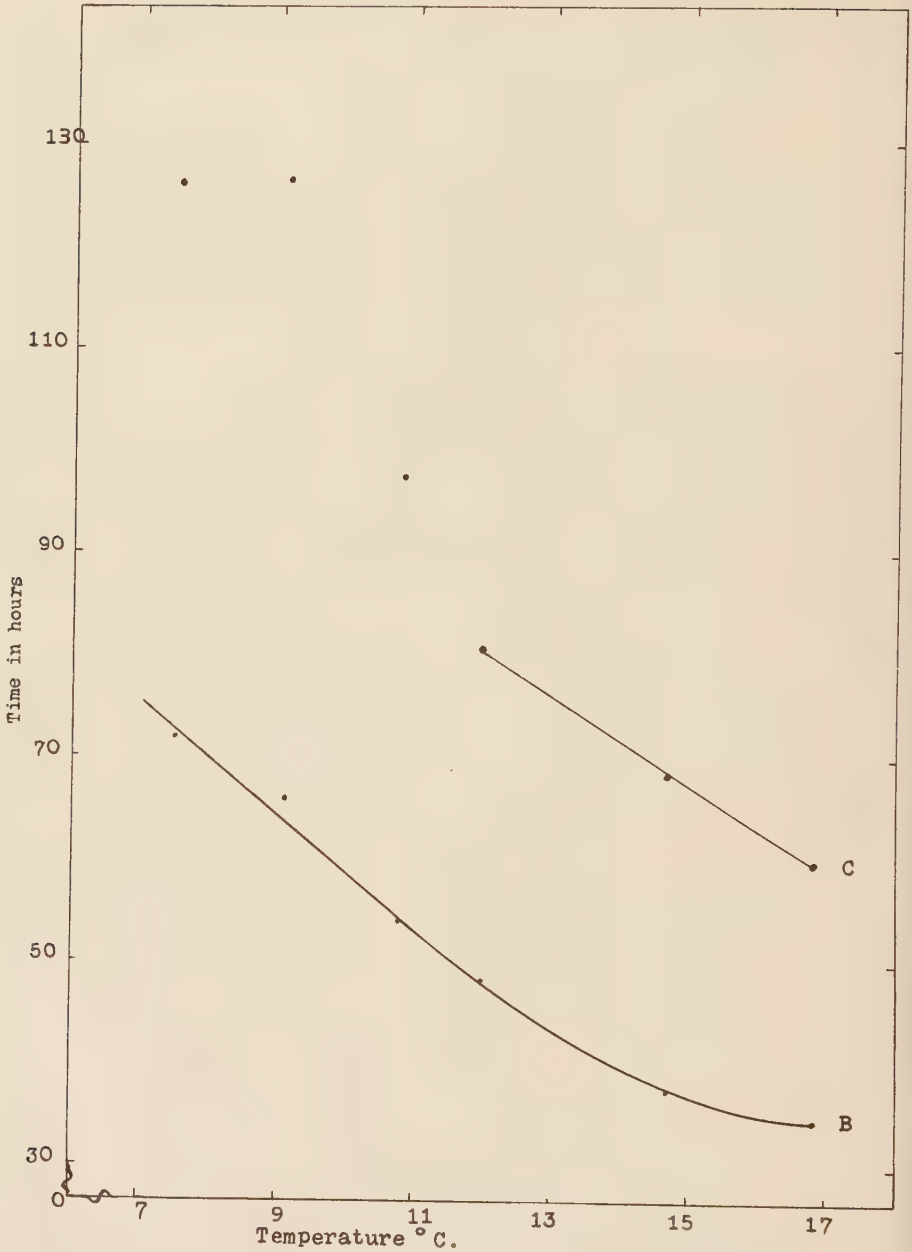

Fig. 1. The rates of development of *Psettichthys melanostictus* to closure of blastopore (B) and hatching (C).

Spawning flounders were obtained aboard a commercial trawler operating in Bellingham Bay, Washington, on March 28, 1935. The fish were carried alive to the Commission's Seattle laboratory. The ova were stripped from a single female into glass culture dishes, fertilized with sperm from a single male, and then placed in the bell jars of the machine. Temperatures of 7.5, 9.1, 10.8, 12.0, 14.7, and 16.8° C., respectively, were maintained in the six compartments of the machine.

Discussion

The development of the ova in each portion of the experiment was carefully observed and the time that each stage appeared was recorded. Periodic samples were taken and preserved. The three stages used in this paper are: stage A, the four-celled; stage B, the closure of the blastopore; and stage C, hatching. The time to hatching is taken as that time when the first ova in the tank hatched. Table 1 gives the time after fertilization that each stage appeared in the various tanks. The ova in the tank maintained at 9.1° C. became very adhesive shortly before hatching and this phenomenon probably caused the hatching result at this temperature to be in error over those where normal hatching was noted.

The ova incubated at 7.5° C. attained the two-celled stage after 3 hours and 37 minutes; the four-celled stage appeared after 4 hours and 35 minutes' incubation. The blastopore closed in 72 hours, and the first ova hatched 126 hours and 11 minutes after fertilization.

Parts of the data from table 1 are presented graphically in figure 1. The data show that the acceleration in the rate of development is greatest for temperature increases between 7.5 and 12.0° C. The curve of the speed with which the blastopore closed as a function of the temperature falls sharply at the higher temperatures.

Johansen and Krogh (1914) found that the relationship between hatching time and temperature was best expressed by a straight line, and Merriman (1936) found that the same was true for the hatching times of the cutthroat trout, *Salmo clarkii clarkii* Richardson. The data shown graphically in figure 1 agree with these findings for the temperatures between 12.0 and 16.8° C., but the straight-line relationship is lost in the three hatchings below 12.0° C. The hatching time for ova incubated at 9.1° C. may be in error from the evident change in the ova themselves which caused them to become adhesive. The divergence of the other two points may result from temperatures of incubation below those that are normal for the species. Merriam (1936) points out the possibility of hatching enzymes acting to cause abnormally early or late hatching. He also mentions that variations in the toughness of the eggshell might also affect the hatching period. These or other factors may have influenced the hatching times of the ova incubated at the three lowest temperatures.

Summary

1. The ova of *Psettichthys melanostictus* were incubated at constantly maintained temperatures of 7.5, 9.1, 10.8, 12.0, 14.7, and 16.8° C.

2. The ova were kept in a pelagic state throughout the period of incubation. This imitated the natural environment of the ova.

3. Increases of temperature influenced the rate of development most between 7.5 and 12.0° C. The curve of the speed of development as a function of the temperature falls sharply at the higher temperatures.

4. The data for the hatching times at temperatures between 12.0 and 16.8° C. are expressed by a straight line. Possible adverse effects of the low temperature on hatching enzymes, or unknown causes, cause the data from the hatching of ova incubated at the three lowest temperatures to diverge from the usual straight-line relationship.

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PACIFIC SALMON IN THE ARCTIC OCEAN

By J. R. Dymond

It is not generally known that at least two species of Pacific salmon are occasionally taken in rivers flowing into the Arctic ocean. Preble (1908) had reports that "occasional specimens of salmon (*Oncorhynchus*) are taken in the Mackenzie. These are said by the traders, many of whom, because of a former residence in British Columbia or on the Yukon are familiar with the salmon, to be identical with the common one of the Yukon." As a result of recent Russian investigations, Borisov (1928) reported that the "dog salmon (*Oncorhynchus keta*) was caught in September in the river Lena at the junction with it of the small stream Kuranakh opposite Bulun." The mouth of the Lena is about two thousand miles west of Bering Strait.

The Royal Ontario Museum of Zoölogy has recently received specimens of the dog salmon (*O. keta*) and humpback salmon (*O. gorbuscha*) from the Mackenzie River. These were sent us by Mr. K. H. Lang of Aklavik. One specimen of dog salmon (R.O.M.Z. No. 10389) was taken in the Peel River, 50 miles south of Aklavik, October 4, 1937. It was a male, 27½ inches long, weighing 7½ pounds. Two specimens of humpback salmon (R.O.M.Z. Nos. 10185 and 10511) were taken, respectively, at Kigtluidt on Richardson Island, September, 1936, male, 2 pounds; and Kittigasuit, August 10, 1938, male, 21½ inches, 3½ pounds.

Both species appear to be rather uncommon in the Mackenzie area although in some years far more are taken than in others. On September 20, 1938, Mr. Lang wrote: "We got quite a few salmon fishing at the coast, about 30 in all, and I hear several more were caught all over the Delta. This is unusual; many natives didn't recognize the fish but others remembered having caught some in other years. One old man told me 'I catchum plenty that kind on the west side of the Delta, 1931.' Later I moved to a place 6 miles north of Kigtluidt, over there I got a few." This account refers to the dog salmon. According to Mr. Lang, a notable run of dog salmon came up the Mackenzie as far as the Arctic Red River and Peel River in 1914. "Some of these salmon were very large, 20–25 lbs., and many of the Indians had seen the same kind on the other side of the mountains in Yukon, but nobody remembers another run like it."

That salmon occasionally penetrate far up the Mackenzie is shown by the taking of a specimen of *O. keta* in the Slave River, five miles below Fort Smith in 1931. The specimen on which this information is based is in the collection of the Royal Ontario Museum of Zoölogy.

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UNDEVELOPED RESOURCES OF THE WESTERN PACIFIC NORTH OF THE EQUATOR

By Albert W. Herre

This very large subject can only be dealt with in a very sketchy manner. This is because of the enormous range of sea covered and the very inadequate amount of factual information available. Besides the shore fisheries of Japan, Korea, and China, already heavily exploited, there are the coastal fisheries of China and the partially developed fisheries of the Philippines, Caroline Islands, Dutch East Indies, British North Borneo, Sarawak, Malaya, and Indo-China.

The most important family of fishes is that of the Clupeidae, using this name in a very wide sense to include not only the true herring and sardine family but also all their immediate allies.

Immense numbers of Clupeidae occur in Japanese waters, and their exploitation has already reached such proportions that the fishery should probably be little or not at all further extended.

In the more southern waters about the Philippines, the East Indies, and the Malay Penisula are enormous quantities of sardines belonging to about fourteen species. As yet only native methods, utilizing outrigger boats, are in use, and most of the catch is dried. At the same time, millions of dollars worth of canned sardines are imported. No attempt has been made to use modern boats and fishing gear, to develop offshore or pelagic fishing, or to develop the canning of sardines on a commercial basis. Neither has the production of oil and edible fish meal or meal for stock feed been attempted. One species, *Sardinella longiceps,* has been known as the oil sardine for more than a century and has been used for oil production on the Malabar coast for a very long time. The canning of various kinds of Clupeidae would make it possible for the largest catches to be handled without difficulty, and would be a boon to the great consuming public.

Anchovies occur in great schools in many localities, but the only place where they are utilized to any great degree is at Makassar, Celebes, where anchovy paste is made. Makassar is outside the region considered, as it is south of the Equator. Not only the canning of anchovies, but the preservation of spiced and pickled anchovies in the manner long followed in the western Mediterranean, and the manufacture of anchovy paste, would seem to be industries capable of development in a number of East Indian and Philippine localities.

The mackerel-like fishes rank next in importance in the western Pacific, especially in Japan.

The Japan mackerel is very abundant in Japanese and Korean waters, southward at least into the Philippines, and east to Hawaii, and little more can be done to develop its fishery. South of Formosa deeper-bodied mackerels of the genus *Rastrelliger* are common, and over a large part of the western Pacific could be caught in sufficient numbers to can. This would involve, of course, the use of more modern methods of capture. The tunas occur over most of the western Pacific, and some kinds are found in very great numbers. In Japanese waters little more can be done to extend their fisheries, while in waters farther south the Japanese have developed the Katsuwonis or oceanic bonito fishery wherever they control. At the same time there are very great areas in the Philippines, Dutch East Indies, and perhaps elsewhere, as in the South China Sea, where tuna and bonito fisheries are little or not at all developed by modern methods. The native methods are good enough in their way, but are confined to the immediate coast. As the members of the tuna family are largely pelagic, it is necessary to use seaworthy power boats capable of cruising a radius of at least 500 miles, if they are to be caught in quantity for canning.

A great many seerfishes or kingfishes, of the genus *Scomberomorus*, are taken in the Philippines and East Indies, mostly by small sailboats near shore. There is good reason to believe that further offshore schools of seerfish could be found in the Kuro Siwo and other currents in the East Indian and Philippine seas. This is a fishery that will have to wait on the introduction of power boats, and the use of drift nets, long lines, and other means than ordinary hand-line trolling.

Accompanying schools of fishes of the tuna family are considerable numbers of swordfish, marlin or spearfish, and sailfish. In the Bonin Islands, and off southern Japan, large numbers of swordfish and spearfish are now taken. Elsewhere in the western Pacific they are only taken by chance, as a rule. It would be possible, in some southern localities at least, to catch them in much larger numbers than at present. The oil from their livers would help to make the fishery profitable, even though the common people do not value the flesh very highly.

All the mackerel-like fishes that form large schools, together with various members of the Carangidae that also go in schools, such as the mackerel scad and others, could be canned and marketed at a low figure. To catch them in quantity means they must be followed up at sea instead of being taken only in inshore waters as at present. Purse nets, drift nets, long lines, and other forms of gear for offshore fishing must be used. Some of them could also be dried and sold at a figure well within the means of the poverty-stricken Malayan masses.

Various members of the Carangidae and Scombridae occur in large schools, which remain offshore ordinarily. They can be taken by purse nets and other forms of fishing gear used by boats operating some distance off the coast. Such fishes as the mackerels, mackerel scad, and various Carangidae could be canned, and marketed at a low figure. They could also be disposed of by drying.

In this connection it is well to note that there is a very great demand for first-class dried fish at a price within the means of the people in all Malayan countries, including the Filipinos, and among the Chinese. The first step in meeting this demand is to produce a better grade of salt at a low price. This should be followed by a great improvement in the technique of drying fish, so as to produce a better quality of food. Some dried fish of excellent quality is produced, but the great bulk of it in the warmer parts of the western Pacific is of poor quality.

One of the most promising groups for possible commercial development is that of the sharks and rays. It is true that a number of small sharks and rays are eaten fresh, and that likewise a number of larger sharks and rays are taken for their fins. Even so, nowhere in the western Pacific is any attempt made to catch sharks and rays in quantity by modern methods and to utilize them fully. To do so would mean to revolutionize the method of catching them, by using gill nets and power boats instead of hook and line and canoes. The skins would then be used to make leather, the fins dried for the Chinese trade, and the oil expressed from the livers for medicinal use. The flesh would be ground, the oil pressed out for use in the arts, and the residue made into fish meal for stock food.

No extended systematic investigations of the fishery resources of the western Pacific have been attempted by any of the countries concerned except by the Japanese. South of Japan proper, the fishery investigation vessels of Formosa have made extended trips throughout the waters from Formosa to and including those of Borneo and Celebes. Elsewhere, Japanese boats have surveyed the region between the Pelew Islands and New Guinea. Every Japanese maritime province maintains one or two fishery investigation boats, and the Formosan government has seven in commission. Yet there is not one belonging to the Philippine, Netherlands Indies, British, French, or Portuguese colonial governments. Most of the Japanese investigations have been concerned with the distribution of bonito, and to a lesser degree with that of tuna.

With the aid of a well-equipped research vessel it might be possible to increase very greatly the present much limited fisheries of snappers, serranids, or sea basses, and sciaenids or grunts. Experimentation with various methods not used at present might bring to light vast undeveloped fisheries. Trawl or long lines, deep-sea lines, purse and round haul seines, trammel, gill, and drift nets should all be tried out wherever they seem at all practicable.

One resource already utilized is that of trepang. This industry is capable, however, of much expansion and very great improvement. The quality of the East Indian and Philippine product is for the most part poor to very bad. Instead of fetching the lowest price, it should bring the highest market price. All it needs is sufficient care in its preparation. In many regions where the proper sea cucumbers are plentiful, no attempt at all is made to prepare trepang. By development in those regions the production could be greatly expanded. I believe that trepang could be marketed as soup, already prepared, instead of being sold in the dried form only. With proper publicity, trepang soup should find a large market among lovers of good food in Europe and America.

Another resource very little utilized as yet is squid, which occur in various seas in great schools. In the dried form they are in demand in China, Japan, and elsewhere. I believe that they also could find a wide market in other countries if they were properly cooked and canned.

The bays, estuaries, and lower reaches of rivers in the Malay Archipelago abound in shrimps, belonging to the genera *Peneus* and *Palaemon*. The different species vary greatly in size. Some are quite small, but others are large and some reach a very large size, and all are edible. Large numbers of certain kinds are taken and the surplus is dried, mainly for export to China. At times considerable quantities are taken in the saline Chanos fish ponds about Manila Bay, Batavia, and elsewhere. It is believed that the culture of shrimps could profitably be undertaken in salt or brackish water fishponds. This should be a very promising field for experiment. Shrimps of the genus *Peneus* are in more saline waters, while those of the genus *Palaemon* thrive in water of low salinity or in fresh water.

Crabs of excellent quality and large size abound in shallow bays and often occur in fishponds. Whether their culture would be commercially profitable is not certain, but it would seem that this should be a good subject for governmental investigation and experiment.

Marine crayfish, marketed as lobsters, occur throughout. In Japan they are abundant in the markets, but I do not know where they are taken. Elsewhere they are not commonly seen in city markets, but are eaten by the fishermen and farmers along shore. In some localities they could be caught in commercial quantities by the introduction of special methods of taking them. At present they are ordinarily taken with fish spears, in shallow water.

Among the most delicious of shellfish are various members of the Scylliidae, or sea mantis group. They are very abundant on coral reefs in many localities and apparently can be taken in large numbers. Two of my men caught between 50 and 60 in an hour or so, on a reef at Sitankai. Whether they could be placed in great city markets in good condition or not I cannot say. As long as crab canning is dominated by the Japanese, using the giant spider crab, it is doubtful if the sea mantis could be canned and sold to compete with Japanese canned crab.

Oysters of several species occur in many regions, scattered over the western Pacific, and are greatly esteemed as food. In Japanese waters much work has been done by various experiment stations, and oyster culture is well advanced. In Chinese and Malayan waters considerable quantities of oysters are taken, but very little has been accomplished in the way of oyster culture. None of the modern developments in oyster culture are followed, although a beginning was made in Manila Bay by Mr. Talavera, of the Bureau of Science. The culture of oysters and perhaps other mollusca by modern methods could undoubtedly be developed into a large industry near all the great centers of population along the coasts and on the islands of southeastern Asia. The crude methods followed by Chinese, Filipinos, and Malays for a very long time demonstrate the feasibility of oyster culture in the warmer parts of the western Pacific.

The culture of pearl oysters in Japan and Celebes is so well established and so well known that nothing need be said of it.

In the waters of the western Pacific several species of whale, as the term is popularly used, occur and also a number of kinds of the smaller whales, from blackfish down to small kinds of porpoises. Some species occur in large schools, and at times schools of incredible size are seen, containing many thousands of individuals. I have traveled for two hours through a school of porpoise moving in the direction opposite to that of our ship, which was traveling at 9 or 10 knots an hour. This school was more than 20 miles long, and 3 miles or more in width; at any time several hundred could be seen at once leaping in the air. At present no use is made of porpoise, but large quantities of oil could be obtained from them, and the carcass could be made into stock feed or fertilizer.

We are often told by people who have no firsthand knowledge of conditions in Oriental tropical waters that they are deficient in fish life. Anyone who reflects on the matter will see that the presence of vast numbers of voracious fish-eating porpoise is an indication of the presence of extraordinary numbers of fish. The great schools of various kinds of tuna and seerfish are also a sufficient index to the presence of immense quantities of smaller fish, such as sardines, on which they feed.

THE FRESH-WATER FISH FAUNA OF CALIFORNIA

By Leo Shapovalov

Introduction and Historical Note

The purpose of this paper is to present the status of our knowledge regarding the fresh-water fish fauna of California and to call attention to some of the problems of its classification. The writer feels that the presentation of these problems is timely, despite the fact that they cannot be solved without much additional study.

Papers dealing with the systematics of the fresh-water fish fauna of California have been written since 1854. Following a long series of descriptions of new forms by Gibbons, Girard, Ayres, and other writers, J. O. Snyder in 1905 began a series of faunistic papers that contain excellent revisions and summarizations embracing most of the groups. However, Professor Snyder made his principal contributions prior to 1920 and the literature published since that time has not kept pace with our added knowledge, not only of the California fauna, but also of the classification and nomenclature of fresh-water faunas generally.

In their distributional list of 1931, B. W. Evermann and H. W. Clark (1931) presented a general summary of the California fresh-water fish fauna, together with a detailed annotated bibliography. However, as so often happens in initial efforts at general summarization, a number of errors and omissions, respecting both distribution and classification, occur in this paper. Especially for the Cyprinidae, the nomenclature used is open to question in some particulars.

General Character of the Fish Fauna

The native fresh-water fish fauna of California, like that of the western United States in general, is not a greatly diversified one, in comparison with those of the eastern United States, Europe, Asia, and other parts of the world. It represents the relict fauna of an arid region. And of the fishes present in the streams of California, a number are anadromous forms or forms able to withstand salt water.

At least as a basis for beginning discussion of the existing problems, a total of 74 species of fresh-water and anadromous fishes may be recognized, without the use of trinomial names. This is three less than the number recognized by Evermann and Clark (1931). These 74 species belong to 11 families, as follows:

1. Petromyzonidae, 2 species (genera *Entosphenus, Lampetra*)
2. Acipenseridae, 2 species (genus *Acipenser*)
3. Salmonidae, 20 species (genera *Oncorhynchus, Salmo, Salvelinus, Prosopium*)
4. Catostomidae, 11 species (genera *Notolepidomyzon, Pantosteus Catostomus, Xyrauchen*)
5. Cyprinidae, 27 species (genera *Orthodon, Mylopharodon, Lavinia, Ptychocheilus, Gila, Pogonichthys, Richardsonius, Tigoma, Siboma, Hesperoleucus, Siphateles, Leucidius, Oregonichthys, Apocope*)
6. Cyprinodontidae, 3 species (genus *Cyprinodon*)
7. Gasterosteidae, 1 species (genus *Gasterosteus*)
8. Centrarchidae, 1 species (genus *Archoplites*)
9. Cottidae, 5 species (genus *Cottus*)
10. Embiotocidae, 1 species (genus *Hysterocarpus*)
11. Gobiidae, 1 species (genus *Eucyclogobius*)

Discussion

Salmonidae.—Of the five species of Pacific salmon which are found on the Pacific coast of North America, *Oncorhynchus tschawytscha* and *O. kisutch* are of some importance in California and are the only forms artificially propagated in the State. *O. gorbuscha, keta,* and *nerka* are rarely found in California.

Although all five of these are valid species, there is strong evidence at hand that several races or subspecies should be recognized. It seems certain that some geographical races exist, but whether the differences between them are genetic or not must be decided experimentally.

At this point it might be well to mention that throughout this paper the writer will use the terms "subspecies," "race," "variety," and "strain" advisedly, and also that other terms, such as "morpha" and "natio," might be the proper terms to apply in order to show clearly the true relationships existing.

The extreme difficulty of separating and defining the various species and geographical races of the genus *Salmo* has long been recognized. However, the California members of the genus may be divided into two natural groups, which are composed of the following species generally recognized at present, listed here with their supposed native distribution.

RAINBOW OR STEELHEAD SERIES

Salmo gairdnerii. All streams entering the Pacific Ocean
Salmo stonei. Upper Sacramento and McCloud rivers
Salmo gilberti. Kern River and possibly other streams draining the southern Sierra Nevada
Salmo agua-bonita. Volcano Creek, south fork of Kern River
Salmo whitei. Upper Kern River tributaries, Soda Creek, Wet Meadow Creek, Coyote Creek, and Little Kern River
Salmo rosei. Lake Culver and neighboring high lakes of the Sierra Nevada
Salmo evermanni. San Bernardino Mountains
Salmo aquilarum. Eagle Lake
Salmo regalis. Lake Tahoe

CUTTHROAT SERIES

Salmo clarkii. Coastal streams south to and including the Mad River
Salmo henshawi. Lake Tahoe and Truckee River basin, Walker and Owens rivers
Salmo seleniris. Headwaters of Silver King Creek
Salmo pleuriticus. Salton Sea, New River, Colorado River

The question of the proper specific name or names to use for the forms of trout variously called "rainbow" and "steelhead" comprises one of our most complex problems. At the start the writer will say that he believes that if one specific name is to be used for this group, that name should be *gairdnerii*. The question of whether the name *gairdnerii* or *irideus* should be applied is not so much one of nomenclature as of zoölogy, and that is the principal reason that so much confusion exists.

At first, ichthyologists in general considered that the forms which we now know as "steelhead" and "rainbow" were different species, and therefore applied the names *gairdnerii* and *irideus*, respectively, to them. When it became apparent that these were merely the sea-run and stream forms of the same species, there arose the problem of which scientific name to apply. *Gairdnerii* is the name first used and, according to the rules of nomenclature, clearly has precedence over *irideus*, providing, and this is the crux of the whole matter, that the name *gairdnerii* was originally applied to a trout of the rainbow-steelhead series. There are a few writers who take the view that the specimen originally described as *Salmo gairdnerii* was not a trout (genus Salmo) at all, but a Pacific salmon (genus *Oncorhynchus*), or the view that the original description is too vague and indefinite to be applied to any species. Most writers, however, now believe that the fish originally described as *Salmo gairdnerii* was a trout and the present writer concurs in this opinion. The original description of *gairdnerii* is not a particularly complete one and it would have been a happy circumstance if Sir John Richardson had ignored the poorly preserved specimen from which he described the species. However, this is a matter now beyond our control, and it appears to the writer that by a process of elimination we must arrive at the conclusion that the fish in question could not have been a Pacific salmon. As has been stated above, the question of *gairdnerii* versus *irideus* is one of identification or, in other words, a zoölogical rather than a nomenclatural one. The International Commission on Zoölogical Nomenclature does not make rulings regarding zoölogical questions and therefore will not straighten out this problem.

It is likely that there are, or at least originally were, different strains or races of *Salmo gairdnerii.* It is possible that the form known as *S. stonei* is such a race. *S. shasta* is also likely such a race, unless it is shown to be a synonym of *stonei,* a distinct possibility. If a synonym, the name *stonei* would have clear priority, being published earlier than the name *shasta.* The scientific name of the original hatchery "rainbow" would then be *Salmo stonei* or *Salmo gairdnerii stonei.*

Although the present writer has not followed a system of trinomial nomenclature in the list previously mentioned, he believes that such a system would best show the true relationships of the various forms of *S. gairdnerii.* Some recent writers have followed a system of trinomial nomenclature for this group for several years (e.g., C. McC. Mottley since 1936). As a matter of fact, David Starr Jordan in 1894 used the names *Salmo gairdneri stonei, S. gairdneri shasta, S. gairdneri gilberti,* and *S. gairdneri agua-bonita,* but recognized *S. irideus* as a separate species. There is some question, however, of whether the time has now come to apply such a system, or whether we should wait until we have a clearer picture of our California subspecies, races, varieties, or strains of *Salmo gairdnerii.*

It is to be noted that in the previously mentioned list only two species of golden trout, *Salmo agua-bonita* and *whitei,* have been named instead of the three described and listed by Evermann and Clark in their 1931 check list. Brian Curtis in 1934 stated that *Salmo roosevelti* is probably no more than a color variation or subspecies of *agua-bonita.* Further investigation may show that *agua-bonita* and *whitei* are not distinct species. If they are not, the next step will be to decide whether all the golden trout should properly be classed as subspecific to *Salmo gairdnerii* or whether they deserve rank as full species.

The writer believes there is a good possibility that *Salmo gilberti* and *evermanni,* and possibly also *aquilarum* and *regalis,* will eventually be considered as subspecific to *gairdnerii,* or, in whole or in part, even relegated to the synonymy of the latter species. These remarks also apply to the one trout described from Lower California, *Salmo nelsoni.*

There is some question whether *Salmo rosei,* a member of the "rainbow" series described from Lake Culver, is a native form or a trout introduced by stocking from a hatchery. In fact, the indiscriminate stocking of various waters of the State with trout from other waters, carried out over a long period of years, has so complicated the racial problem that it may now be impossible to solve it completely.

The genera *Salvelinus* and *Prosopium* are each represented by a single native form in California. Each has a comparatively limited distribution within the State. The Dolly Varden Trout has variously been called *Salvelinus malma, Salvelinus spectabilis,* and *Salvelinus malma spectabilis.* There is some question whether the group *Prosopium* should be recognized as a full genus or as a subgenus of *Coregonus.* Most American ichthyologists now consider it a full genus, while European workers give it subgeneric status.

Catostomidae.—Three California drainage basins, the Sacramento, Klamath, and Lahontan, each contain a coarse-scaled species and a fine-scaled species of the genus *Catostomus.* There is likelihood that a form found in the Owens River system on the east slope of the Sierra Nevada is subspecifically or even specifically distinct from *Catostomus arenarius.*

Cyprinidae.—The systematic status of a number of species now generally recognized is very uncertain, especially of the forms usually referred to the genera *Cheonda, Tigoma, Siboma, Hesperoleucus, Siphateles,* and *Apocope.* The use of some of these generic names is questionable. For example, it has been shown that the type on which the genus *Cheonda* was based, *Cheonda cooperi,* is a generic hybrid, and it is therefore doubtful that the name *Cheonda* should be used in place of *Richardsonius.*

The genus *Apocope* in California has lately been studied by Alex J. Calhoun. It appears that the farther studies on this group are carried, the more complex the problem of classification becomes. *Apocope robusta, carringtoni,* and *klamahensis,* of the Sacramento, Lahontan, and Klamath systems, respectively, are very much alike. It seems that, without resort to trinomial nomenclature, representation of the true relationships of this group is very difficult or impossible, unless we lump a number of local variants into one species. The same remarks apply to most of the widely distributed fresh-water fishes of California.

Siphateles formosus, obesus, and *bicolor,* of the Sacramento, Lahontan, and Klamath systems, respectively, are very similar.

But little attention has been paid to the possibilities of hybridization of California cyprinids under natural conditions and it is probable that one or more of the species described are generic hybrids. For example, the writer has at hand specimens which indicate that *Richardsonius egregius* may hybridize with *Siphateles obesus.* Other specimens indicate that *Richardsonius microdon,* from Lake Tahoe, is a synonym of *Richardsonius egregius.*

Cottidae.—Five species of *Cottus* may be recognized, although more have been described. It is possible that one or more of these five are not valid species; at the same time, several supposedly new forms have been collected but not yet described. Even when these forms are described and the purely nominal species eliminated, nomenclatural problems are likely to arise. When we consider the forms present in small streams not parts of a larger river system, for example, the coastal stream Waddell Creek in Santa Cruz County, we find forms that apparently do not intergrade and may be recognized as valid species. But when we consider a large river system, the Sacramento, we encounter a complex of forms that to date has formed a mosaic the parts of which have not fitted together in a smooth manner. From some widely separated points we find forms that are almost exactly alike, while from some points close together we find forms apparently distinct. Which of these should be recognized as full species, which given the status of subspecies, and which recognized in other ways, remains a problem despite a fair amount of work.

The forms described as *Cottus shasta, asperrimus,* and *macrops* may be synonyms of various specimens now grouped under the name *Cottus gulosus. Cottus klamathensis* of the Klamath River and *C. beldingi* of the Lahontan system are also distinguished with difficulty from specimens labeled *Cottus gulosus* and may not warrant specific rank. However, there is good reason to believe that not all the specimens now labeled under the name *Cottus gulosus* in the various collections belong to the same species.

Cyprinodontidae.—Three species are provisionally listed here, *Cyprinodon macularius, nevadensis,* and *diabolis,* but it appears that there are a number of somewhat varying but closely related forms. Their exact status is yet to be determined. Other forms which have been described but are not listed here are *Cyprinodon browni* and *C. californiensis.*

The Empetrichthyidae, listed by Evermann and Clark in their 1931 list as being represented in California by *Empetrichthys merriami,* are no longer recognized as a separate family, and were included in the Cyprinodontidae by G. S. Myers (1931). The specimens on which the locality records were based were actually taken at Kings Spring and Pahrump Spring in southwestern Nevada.

Other families.—The systematic status of the native fresh-water Gasterosteidae, Centrarchidae, Embiotocidae, and Gobiidae is relatively clear, as might be expected in view of the representation of each family apparently by a single species. However, even within these groups controversies have arisen from time to time and but little investigation has been made of the possibilities of existence of subspecific forms within the latter three families.

INTRODUCED FISHES

A number of fishes have been introduced into the State and some of these have established themselves quite firmly in its waters. Most of them are listed by Evermann and Clark (1931) and a detailed account will not be given in the present paper. Practically all the exotics are forms which cannot be expected to hybridize with native fishes under natural conditions, so they will not affect the native fauna in this manner. However, by their presence they have influenced the environmental factors affecting the native fishes in such a way as to change the distribution and numbers in some instances.

Among the introduced forms, the scientific names of the species often known as *Micropterus salmoides, Roccus lineatus,* and *Salmo trutta* have been subject to recent discussion. The systematic position of the various populations of fishes that may be grouped under the name *Salmo trutta,* inhabiting the streams of Europe, is in many respects comparable to that of the populations which may be grouped under the name *Salmo gairdnerii.* There are both mature sea-run and mature stream populations of each. If the form known as *Salmo levenensis* was in its native habitat a species distinct from *trutta,* which is doubtful, its representatives in California can no longer be recognized, because of continued hybridization in the course of artificial propagation.

CHANGES IN THE FAUNA

The character of the native fauna has been changed not only by the introduction of fishes, but also by man-made changes in environment. Lumbering, agriculture, and power development have played dominant rôles in changing the character of many streams and lakes, with consequent changes in the character of the fish fauna.

Various factors, such as overfishing, changed environment, and introduction of exotic species, have contributed to the depletion of some species. At the same time, artificial stocking, mostly with various species of trout and salmon, has extended the range of some species and has also populated rather large areas formerly devoid of fish life.

SUMMARY

In summing up the status of classification of the California fresh-water fish fauna, it may be said that although a number of species is now generally recognized, past attempts at systematic treatment have been far from satisfactory, largely because they have been founded upon insufficient material and not subjected to statistical analysis. The problems are further complicated and some of them may even now be impossible to treat satisfactorily because of the depletion or possibly extermination of certain forms of restricted distribution, and also because of the unnatural hybridization of such forms. Such hybridization has taken place through (1) hybridization during artificial propagation in hatcheries, (2) hybridization in the streams and lakes of native with introduced forms, and (3) hybridization of local forms through the mixing of waterways by the construction of mining and other diversions. The remarks under (3) apply especially to the genus *Salmo*, but are true to a greater or less extent as regards other groups.

We may never determine with certainty, then, what existed originally, nor may we be able to say which of our present forms are true representatives of the original species and races and which are hybrids. The confused status of the classification of California fresh-water fishes and the difficulties just cited, which stand in the way of our satisfactory solution of the problems, may seem discouraging, and sometimes even insurmountable, but the writer believes that we should accept the challenge and strive to solve the problems through (1) a critical examination of the published literature, (2) statistical analysis of sufficiently large numbers of specimens, where necessary, and (3) experimental work to determine the genetic character of subspecies forms.

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SOME FACTORS INFLUENCING QUANTITY MEASUREMENTS OF LARGE VOLUMES OF FISH OILS

By Neal M. Carter

Fish oils constitute an important article of international commerce and are usually shipped in bulk quantities too great to admit of direct determination of these quantities by the most satisfactory method of evaluation, namely, weighing. Consequently, such bulk quantities are almost always estimated by direct measurement of the volume, or from the capacity rating of upright storage tanks, shaped tanks in the hold of a vessel, or horizontal tank cars. Relatively rarely, flow meters are used to measure directly in units of capacity (gallons or liters) quantities of fish oils being transferred from one tank to another, or, more rarely still, pressure gauges at the bottom of an upright tank are used to determine the weight of the contents.

On this continent, and in many countries to which Canadian and American fish oils are shipped, the volume or capacity measurement is acceptable to the trade after expressing any volume in terms of capacity and relating the capacity to the weight, that is, by the use of a unit such as the American (U.S.) gallon at 60° F. (15.56° C.) having a stated weight in pounds. This convenient practice necessitates assuming an average specific gravity or density for the oil, and incurs an application of a coefficient of cubic expansion for the oil if the volume or capacity measurement is determined at a temperature other than the agreed standard temperature. In commercial practice in British Columbia, herring, salmon, and dogfish oil are all assumed to weigh 7.71 pounds per American gallon at 60° F., though pilchard (sardine) oil is differentiated as weighing 7.7417 pounds per American gallon at 60° F. To all four oils there is officially assigned a coefficient of cubic expansion of 0.000404 per degree Fahrenheit, since this factor is incorporated in all of Lloyd's tank charts accepted as standard. In practice, the coefficient 0.0004 is used. Differences in measurement procedures and interpretation of the factors named above, complications introduced by the use of Imperial, American, metric, or other units in various countries, and the ignoring of certain phenomena characteristic of fish oils have led to more than one controversy between buyers and sellers of shipments of oils.

Uncertainty concerning what divergences from the accepted specific gravities might be encountered, and doubt concerning the general applicability of the stated coefficient of cubic expansion, led to a request from a Vancouver, Canada, firm of commercial analysts to have the Pacific Fisheries Experimental Station at Prince Rupert, B. C., investigate these properties in several British Columbia fish oils. The present paper summarizes the findings on pilchard and herring oils and points out several observations on the behavior of these oils toward temperature changes.

Specific gravity.—The specific gravity of six samples each of British Columbia crude pilchard and herring oils obtained from various sources at different times of the fishing season was shown to range between the limits:

Pilchard oil at 60° F. (15.56° C.)	Herring oil at 60° F. (15.56° C.)
s.g. = 0.921 to 0.937, or	s.g. = 0.920 to 0.927, or
7.68 to 7.80 lb. per U. S. gal.	7.67 to 7.72 lb. per U. S. gal.
9.21 to 9.37 lb. per Imp. gal.	9.20 to 9.27 lb. per Imp. gal.
0.919 to 0.935 kilo. per liter	0.918 to 0.925 kilo. per liter

The ranges of specific gravity encountered encompass the values of 7.7417 and 7.71 pounds per American gallon at 60° F. assumed commercially for pilchard and herring oils, respectively.

Coefficient of expansion.—By means of dilatometric measurements under carefully controlled temperature conditions, the pilchard-oil samples exhibited an average coefficient of cubic expansion of 0.000441 per degree F. (0.000794 per degree C.) throughout the temperature range 100° to 32° F. (38° to 0° C.). Below 32° F. the separation of a solid phase (stearine) commenced before temperature equilibrium could be established. The herring-oil samples exhibited an average coefficient of 0.000416 per degree F. (0.000749 per degree C.) throughout the temperature range 100° to 60° F. (38° to 16° C.), below which stearine commenced to separate. Both these coefficients are higher than the accepted coefficient 0.000404 per degree F. (0.000727 per degree C.) at present in use for these oils.

In expressing a volume of *completely liquid* oil, measured at its random temperature, in terms of weight of that oil at a standard temperature, it will be observed: (1) that an error of one degree F. in measuring the average temperature of the volume of oil introduces in the computed weight an error of about 0.04 per cent (0.07 per cent for one degree C.); (2) that in using a faulty specific gravity the error introduced in the computed weight is about 0.1 per cent for each discrepancy in the third decimal place of that factor; and (3) that in using a faulty coefficient of expansion, the error introduced in the computed weight is 0.0001 per cent for each discrepancy of one unit in the sixth decimal place of that coefficient, per degree F. of temperature difference.

The magnitude of the above-indicated errors can be minimized by obvious expedients if desired; but other, quite appreciable, errors in weight estimation may be encountered if stearine is present in the oils. The effect of stearine separation on the specific gravity and coefficient of cubic expansion was therefore investigated, since in commercial practice quantities of pilchard and herring oil must frequently be measured at temperatures that permit a very appreciable proportion of stearine to be present in a mobile oil, or the oil may even be semisolid. Attention has already been drawn to the possible errors introduced by stearine formation in sardine, pilchard, and sperm-whale oils.[1]

Effect of stearine separation on specific gravity.—A typical sample of crude pilchard oil was allowed to stand at about 37° F. (3° C.) until an amount of compact stearine equal to 50 per cent by weight of the oil could be separated by centrifuging. The following specific gravities were observed at 60° F.:

Original crude pilchard oil (clear)	0.93316
Oil separated from deposited stearine	0.93081
Deposited stearine (semisolid at 60° F.)	0.937
Oil remixed with stearine (suspended)	0.936

Some estimate of the probable effect of stearine deposition on the specific gravity of pilchard oil may be gained by relating the foregoing data to the following table showing the percentage of stearine separated from pilchard oil at various temperatures:[2]

Temperature F.	77°	66°	57°	50°	46°	43°
Temperature C.	25°	19°	14°	10°	8°	6°
Percentage of stearine	4	9	16	29	54	54

A pronounced hysteresis in the temperature-time relations of stearine content of certain fish oils is well recognized commercially with respect to pilchard and herring oils and may be attributed partly to supersaturation during slow cooling and the presence of oxidized products.[3] This phenomenon made possible the following observations on a typical sample of crude herring oil. The clear oil at 60° F. was allowed to stand at that temperature until no further stearine deposited as indicated by the dilatometric volume (24 hours), and the sample was then held at 32° F. for a further period of 24 hours, by which time it was practically solid. On warming to 60° F. and holding at that temperature until the volume remained constant, it was evident that much more stearine was present than formerly. Specific gravity determinations gave the following values at 60° F.:

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[1] E. R. Boulton and K. A. Williams, Analyst, 60:158, 1935.

[2] H. N. Brocklesby and O. F. Denstedt, Bull. Biol. Bd. of Canada, 37:73, 1933.

[3] W. Clayton *et al.*, Nature, 138:801, 1936.

Clear herring oil (supersaturated)	0.9246
Oil in equilibrium with stearine after standing	0.9281
Oil in equilibrium after cooling and warming	0.9308

It is clear from this experiment that the previous thermal history of the oil has a considerable effect on the specific gravity as determined at the prevailing temperature or at some standard temperature. As already indicated, the calculated weight of a measured quantity of this oil could vary as much as 0.6 per cent, depending on whether the volume of the oil was measured at 60° F. after cooling or warming to that temperature. The rate of warming or cooling has a decided effect on the amount of stearine present as well as the specific gravity of the stearine.

In a second typical sample of crude herring oil it was shown that spontaneous deposition of stearine commenced at 77° F. (25° C.) during very slow cooling; on warming the sample equally slowly, the last trace of stearine dissolved at 95° F. (35° C.). The latter temperature corresponds very closely with the temperature indicated for initial stearine deposition in the absence of supersaturation. This point could not be determined experimentally, but was estimated by plotting a curve of contractions in volume of oil (dilatometric) due to stearine formation at five equilibrium temperatures and extending this curve to the temperature of zero contraction. The percentage of stearine formed at increasingly lower temperatures (2.2 per cent at 68° F., 5.6 at 58° F., 20 at 40° F.) is apparently less than at the similar temperatures quoted above for pilchard oil; the methods of estimation in the two series were different, however, and the occlusion of still liquid oil in the stearine renders any exact separation and determination of the stearine very difficult. By a special method of separation the author has demonstrated that approximately 75 per cent of solid stearine and 23 per cent of clear oil can be obtained from crude herring oil at 5° F. (—15° C.).

Effect of stearine separation on coefficient of cubic expansion.—Several series of dilatometric experiments involving slow cooling and warming were undertaken. The extra contraction due to stearine formation, superimposed on the ordinary contraction due to cooling, proceeded rather irregularly. This irregularity on cooling was attributed to a combination of at least three probable causes: (1) supersaturation, (2) progressive separation of different types of solid glycerides, and (3) conversion of these glycerides into different crystalline modifications. The irregularity on warming was not so pronounced, probably from the absence of supersaturation. The temperature-volume curve for cooling could never be made to coincide with the curve for warming so long as stearine was present, and at several temperatures the difference in volume was of the order of 0.3 per cent.

From the slope of temperature-volume increase curves (fig. 1) it was demonstrated that the deposition of stearine in pilchard and herring oils gradually increased the coefficient of cubic expansion per degree F. from the given values of 0.000441 (pilchard) and 0.000416 (herring) for the completely liquid oils, to a value that approached 0.00061 per degree F. (0.00110 per degree C.) as the oils became almost solid (32° F.). This coefficient is slightly higher than that obtained by Boulton and Williams[4] for sardine oil containing

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[4] See note 1 above.

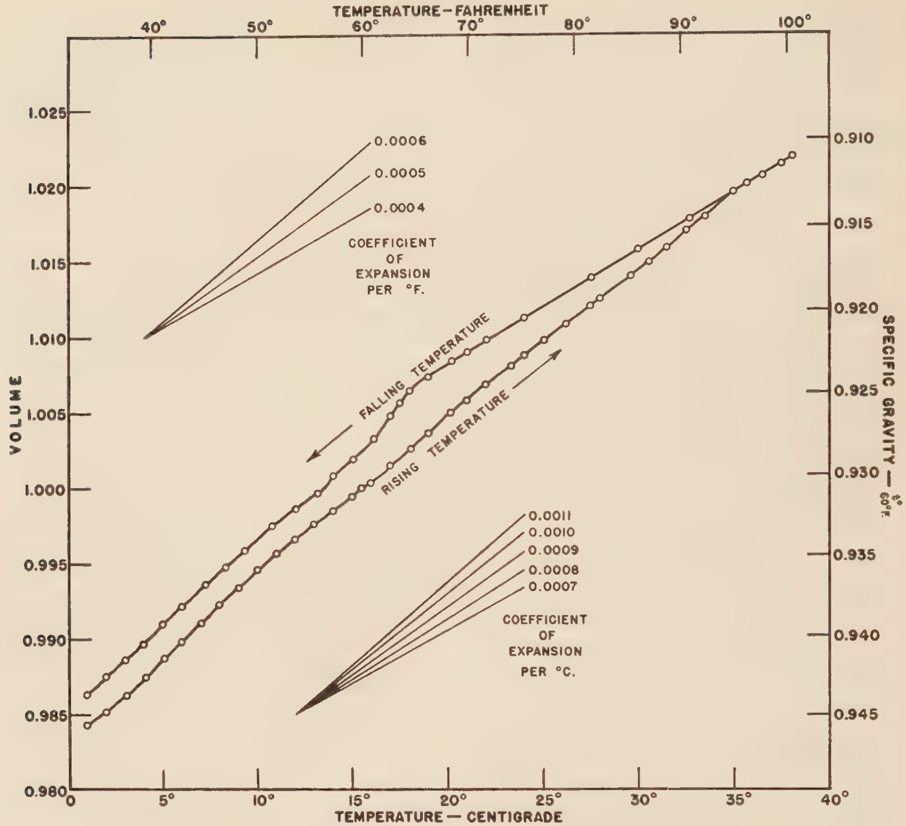

Fig. 1. Temperature-volume curves of a sample of British Columbia crude herring oil subjected to very slow heating followed by cooling. The coefficient of cubic expansion is indicated by the slope of the curves.

stearine, but is considerably lower than the coefficient 0.00105 per degree F. given for crude sperm oil containing stearine (spermaceti).

Using the accepted coefficient 0.000404 instead of the true coefficient 0.00061 when calculating the gallonage of a tank of crude herring oil at 60° F. after measuring the volume of the oil at 35° F. when large amounts of stearine would probably be present, would introduce an error of 0.5 per cent in the computed gallonage. This error would be additive to the previously mentioned error of about 0.6 per cent introduced if the difference in specific gravity of the liquid oil and the oil containing considerable stearine at 60° F. were neglected. Thus a total error of about 1.1 per cent in the gallonage (or weight) of a shipment of herring oil is possible through the use of fixed arbitrary factors.

From the foregoing data it is evident that in dealing with large volumes of oil incapable of being weighed, the estimation of the true quantity of oil from volume measurements made under the prevailing temperature and physical conditions of the oil necessitates a knowledge of the behavior of the oil under changing temperature conditions. If any stearine is present when the volume is measured at a temperature other than the standard temperature, reduction of volume to the volume at the standard temperature should employ a coefficient of expansion chosen in relation to an estimate of the percentage of stearine present (see fig. 1), whether this stearine is uniformly suspended or has tended to concentrate at the bottom of the container. If the weight enters into the transaction, it is advisable that all parties concerned come to some agreement regarding the weight of the unit of capacity or volume employed and the physical condition of the oil when this was determined, for it has been shown that this weight at an agreed temperature can vary with the amount of stearine present. The various specific gravities indicated for pilchard and herring oil containing stearine and no stearine at 60° F. may serve as a guide; but more accurate results will be obtained from actual specific gravity determinations carried out at the standard temperature on a total vertical sample of the oil in the container after melting any stearine withdrawn with the sample.

Other factors influencing volume.—Several factors involved in measurement of the volume may introduce further errors in ascertaining the quantity of oil held in large tanks. Certain of these are difficult of estimation, others may be minimized by simple expedients, and some tend to cancel mutually. Attention is here drawn to:

1. Froth obscuring the true surface of freshly pumped oil.
2. Suspension of air bubbles in freshly pumped cool or stearine-containing oil. In an actual determination, an apparent volume 0.4 per cent greater than the true volume was observed in a cylinder of herring oil that had been agitated and allowed to stand undisturbed overnight at 50° F. (10° C.).
3. Expansion and contraction of the container. A cylindrical steel tank 20 feet (6.1 meters) in diameter filled with oil to a height of 20 feet contracts sufficiently during a temperature decrease of 45° F. (25° C.) to cause a rise of 0.12 inch (3 mm.) in the level of the soil. This rise represents a fictitious increase of 7.7 U.S. gallons (29 liters) in the volume.
4. Deformations of the container due to pressure of the contained oil. In a steel tank of the dimensions given in the preceding paragraph, it has been demonstrated that deformation on filling with oil resulted in a decrease of 0.3 inch (7.6 mm.) in the vertical distance between a striking plate at the bottom and a punch mark at the top of the tank.

THE CONTENT OF CERTAIN AMINO ACIDS IN THE EDIBLE PORTIONS OF FISHERY PRODUCTS

By S. R. Pottinger and Willis H. Baldwin

Introduction

Certain nitrogen compounds, called proteins, must be included in the human dietary in order to permit normal growth and well-being. These compounds may be derived from either plant or animal sources. The food value of the different proteins varies greatly, however, and may be either of excellent or inferior quality. A review of the literature indicates that this quality factor depends largely upon the differential amino acid content of the protein. Experimental feeding tests have shown that an adequate supply of certain of the amino acids must be present in the diet. Some 23 different amino acids have been isolated from the proteins of animal and vegetable origin, but only 10 have been determined to be essential for growth and maintenance. An excellent quality protein is one which contains all the so-called essential amino acids in sufficient amounts to promote optimum metabolism. Poor quality proteins are those which are deficient in one or more of these acids.

Although feeding tests have been used to determine the nutritive value of a large number of proteins, little information is available concerning the amino acid content. The knowledge of the amino acid content is desirable in order to determine the supplementary value of the various proteins in the preparation of balanced diets. Deficiencies may be adjusted by supplementing inadequate proteins with others having sufficient amounts of the particular indispensable amino acid required.

Fish proteins, as a class, have been found to be of high nutritive quality. Holmes (1918) found fish proteins to be highly digested by man, and Drummond (1918) showed that the coagulable proteins of fish possess as high nutritional value as those of beef. Jones (1926) reports that "the proteins of clams, shrimp and oysters compare favorably with the proteins of other articles that are highly regarded for their nutritive value." Feeding experiments in general have shown fish to be a most valuable food.

So far as chemical composition is concerned, very little information is available in the literature relative to the amino acid content of fish proteins. Osborne and Heyl (1908) report the content of several of the amino acids in halibut. Osborne and Jones (1909) determined the percentages of a number of amino acids in scallop muscle and reported that they found more arginine and less lysine in scallops than in halibut. Jones, Moeller, and Gersdorff (1925), working with shrimp muscle, determined cystine, arginine, histidine, and lysine by the Van Slyke method, and cystine, tryptophane, and tyrosine by colorimetric determinations. Rosedale (1929) determined the diamino acid content of several fish tissues by Van Slyke's method and in a few cases by Kossel's method. He reports that "the value for diamino acid nitrogen in the flesh muscles of fish appears to be higher than that previously obtained for mammalian tissues."

Rosedale and Morris (1930) found an increase in histidine nitrogen and a decrease in lysine nitrogen in the lower organisms, in which are included oysters and sponge. Abderhalden, Baertich, and Ziesecke (1936) made a study of codfish protein, using the ester method, and reported the content of a large number of amino acids.

Although there are various references to the amino acid content of a few species of fish and shellfish, apparently no general compilation has been published in recent years giving the content of certain of the amino acids for a large number of species. Because of a desire for this information by investigators in the field of nutrition, the Bureau of Fisheries undertook the quantitative estimation of several of the essential amino acids in a large number of the more important species of fish and shellfish.

THE RÔLE OF PROTEINS IN THE DIET

For proper growth and maintenance of the body, certain food components such as proteins, carbohydrates, fats, vitamins, and minerals must be supplied by the diet. Each of these has its specific function in maintaining health. Although fish, shellfish, and crustacea are usually included in the diet as a source of protein, they also serve to furnish other food essentials, particularly vitamins and minerals. Inasmuch as this investigation is limited to a study of fish and shellfish proteins with respect to amino acid content, it might be well to discuss briefly the nature of protein material and its function in the diet.

If living matter, either of plant or animal origin, is extracted with certain solvents, the fats and lipods, carbohydrates, and other substances are removed, leaving a white amorphous mass which contains protein and ash. Upon analysis, the organic portion will be found to be composed principally of nitrogen, carbon, hydrogen, and oxygen and, in some instances, with varying but usually small amounts of phosphorus, sulfur, iodine, and certain other elements. Proteins are found in plants and animals in varying quantities; flesh contains a fairly high percentage in the dry matter, while cereal grains contain only a small amount.

Many kinds of proteins have been isolated in the pure form, such as globin, from the hemoglobin of red blood cells; serum albumin and serum globulin, from blood serum; ovalbumin, from eggs; casein, from milk; gliadin, from wheat; zein, from corn; legumin, from beans and peas; collagen and gelatin, from bones; and keratin, from hair and hoofs. This indicates that proteins are widely distributed in nature and are essential to life.

Although vegetable life can make or synthesize protein material from the chemical elements obtained from the ground and air, the animals cannot synthesize all the necessary amino acids and therefore must obtain certain essential ones from the protein material of the diet. During digestion, this protein is broken down or hydrolyzed into its constituent amino acids. These amino acids are then absorbed into the blood stream and carried to the various tissues of the body, where they are temporarily stored. The cells then select and remove the amino acids which are necessary for the repair or growth of new tissue. Therefore, the main function of the proteins in the diet is to supply amino acids which furnish the "building stones" used to repair tissues destroyed during metabolism or to build new body tissues. A large part of the protein of ingested food, however, may be utilized to yield energy when the fat and carbohydrate intake is inadequate.

Since all body cells are continually undergoing wear and tear, they must be rebuilt in order that the animal may continue to thrive. In growing animals, not only must the body cells be rebuilt as rapidly as they are destroyed, but there must also be an actual increase in the total number of cells in the body. The result will be an increase in weight. Although the available amino acids are absorbed by the tissues after a meal, only certain of them are essential for the growth or repair of the cells. The absence of any one of these indispensable amino acids will inhibit the formation of any new protein or cells. Information regarding the amino acid requirements has been obtained by feeding experiments with purified proteins deficient in certain of the amino acids or by feeding amino acid mixtures. By means of such experiments the amino acids which are necessary to animal life have been determined.

The following amino acids are considered to be indispensable for growth or maintenance: arginine, histidine, lysine, tryptophane, methionine, phenylalanine, threonine, leucine, isoleucine, and valine (Rose, 1937). In the absence of arginine, growth is possible, but only at a subnormal rate. The history of the metabolism of some is uncertain, while still others are definitely known to be synthesized by the body. In the present investigation, quantitative determinations were restricted to the estimation of arginine, histidine, lysine, tryptophane, and cystine.

PREPARATION OF SAMPLES

Because of the perishable nature of fish and the rapid decomposition of the proteins, it was impractical to use raw samples for the analyses in this investigation. Furthermore, certain difficulties in procedure may be encountered because of the high water content and, in some instances, the high oil content of the product.

Decomposition of protein material is brought about principally by enzymic and bacterial action. However, a relatively high water content of the material is essential for maximum decomposition; removal of most of the water will reduce the decomposition to a minimum. Heating protein material in order to drive off the water is impractical where large samples are desired; also, the composition of the protein will most likely be altered by the effect of the heat. Accordingly, a solvent method was used for preparing the samples, dehydration being affected by extraction of the raw fish flesh with anhydrous acetone. This solvent, besides removing water, also dissolves the fat which is present in the body tissues of the fish, producing a final product having a low water content and containing practically no fat.

The samples of fish were prepared from skinned and boned fillets. The samples of shellfish proteins were prepared from the edible portion. Both kinds of raw material were ground in an ordinary meat chopper. Representative samples were assured by using 100 pounds of fish or shellfish for the preparation of each lot of dried material.

The ground flesh was placed in suitable containers, covered with anhydrous acetone, and allowed to stand overnight. This preliminary treatment removed a large part of the water and oil. The solution was drained off and the partly extracted flesh was further extracted for approximately 14 hours in a metal extraction apparatus specially devised for the purpose (Lemon, Griffiths, and Stansby, 1936). Following this treatment, the material was dried by spreading it out in thin layers over a steam bath. The resulting dry fat-free tissue was then ground in a laboratory mill and stored in evacuated glass jars until ready for analysis. The final product was a white, very light weight, coarse powder.

ANALYTICAL PROCEDURE

Methods for the quantitative determination of each amino acid obtainable from a given protein are so time consuming that data of this kind can be obtained only very slowly. However, as only a few of the so-called essential amino acids were determined in this investigation, the problem was somewhat simplified. Although several methods are in use for the quantitative estimation of the various amino acids, the figures obtained by these different methods are not strictly comparable; but in all probability any one of the methods would produce results that are at least relative.

ESTIMATION OF ARGININE, HISTIDINE AND LYSINE

Some methods for the quantitative estimation of amino acids are based on calculation of the quantity of an amino acid from the nitrogen content of certain fractions of the hydrolyzed protein. These methods tend to overestimate the quantity because the calculations are based on the total amount of nitrogen found, whereas some part of this nitrogen may be from a source other than that which is desired. The method selected in this investigation for the estimation of arginine, histidine, and lysine depends on the quantitative isolation of the specific amino acid salts. The values obtained are more likely minimal, as inevitable losses occur in the separation and purification.

The method used was essentially that of Block (1934), with modifications as follows: (1) the silver salt of histidine obtained by precipitation with barium hydroxide was suspended in sulfuric acid at approximately pH 4.0 and reprecipitated; (2) the lysine phosphotungstate precipitate was allowed to crystallize in a refrigerator for at least 36 hours; (3) the lysine phosphotungstate precipitate was decomposed with an excess of hot saturated barium hydroxide solution and the precipitate washed several times with dilute barium hydroxide solution; (4) approximately only two-thirds of the calculated amount of picric acid was added for the first crystallization of lysine picrate; and (5) the lysine picrate was allowed to form in the refrigerator overnight.

Ten-gram samples were hydrolyzed with dilute sulfuric acid for a period of 24 hours.

ESTIMATION OF TRYPTOPHANE

The procedure of Folin and Ciocalteu (1927) was used for the estimation of tryptophane. From the standpoints of rapidity and duplicability of results, it appears to be best fitted to the needs of this problem. This is a colorimetric method based on the reduction of a so-called phenol reagent by the indole nucleus of tryptophane.

Hydrolysis of the protein samples was accomplished by boiling with 20-per cent sodium hydroxide solution for 20 hours.

ESTIMATION OF CYSTINE

Cystine was determined by the method of Sullivan and Hess (1930). This method is colorimetric and depends upon the production of a red color when cysteine, which is produced by the reduction of cystine with sodium cyanide, reacts with naphthoquinone under certain specified conditions. The hydrolysate was usually highly colored and made the color comparison difficult.

Discussion of Data

The natural proteins from most sources contain practically all the amino acids which have so far been identified. In some proteins, however, certain of the known amino acids are lacking entirely, at least so far as present methods of analysis can detect. An example is the well-known animal protein, gelatin, which is deficient in tryptophane.[1] Other proteins are known to contain only a very small amount of certain of the acids, as, for example, some of the vegetable proteins. Zein, from corn, contains a very small amount of tryptophane; and gliadin, from wheat, is deficient in lysine.

The data in table 1 show the proteins of fish, shellfish, and crustacea, as a group, to be good sources of the essential amino acids arginine, histidine, lysine, tryptophane, and cystine. Those of blue crab and shrimp are excellent sources of arginine, and those from halibut and red snapper are also comparatively rich in this amino acid. Boston mackerel, oyster, silver salmon, cod, halibut, and mullet proteins are good sources of histidine.

Lysine is found in large amounts in the proteins of shrimp, lake trout, Bos-

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[1] The data pertaining to tryptophane analyses included in this paper were incorporated in a thesis submitted by Willis H. Baldwin to the Graduate School of the University of Maryland in partial fulfillment of the requirements for the degree of Master of Science, June, 1937.

TABLE 1

Percentage of Arginine, Histidine, Lysine, Tryptophane, and Cystine in the Proteins from the Edible Portions of Fish, Shellfish, and Crustacea

Species	Scientific name	Date sample was prepared	Arginine	Histidine	Lysine	Tryptophane	Cystine[a]
	Fish						
Catfish	Ameiurus catus	Aug. 1937	....	....	....	0.97	....
Cod	Gadus callarias	June 1936	5.58	1.72	6.83	1.06	1.41
Croaker	Micropogon undulatus	May 1936	5.81	1.37	6.10	1.24	1.15
Haddock	Melanogrammus aeglefinus	Sept. 1935	5.70	1.17	6.41	0.85	1.16
Halibut	Hippoglossus hippoglossus	Dec. 1936	6.00	1.66	6.16	1.64	1.45
Herring:							
Lake	Leucichthys artedi	Nov. 1937	....	....	....	1.25	....
Sea	Clupea harengus	March 1937	5.09	1.56	7.03	1.23	....
Lake trout	Cristivomer namaycush	June 1937	5.73	1.40	7.15	1.17	....
Mackerel:							
Boston	Scomber scombrus	Aug. 1936	5.78	1.93	7.13	1.36	1.18
Spanish	Scomberomorus maculatus	Jan. 1936	5.27	1.48	6.53	1.37	1.25
Mullet	Mugil species	Feb. 1937	5.78	1.61	6.74	1.36	1.29
Pilchard	Sardina caerulea	March 1937	5.60	1.23	6.78	1.30	....
Red snapper	Lutianus blackfordii	Nov. 1936	6.18	1.57	6.72	1.22	1.29
Salmon:							
Chum	Oncorhynchus keta	May 1938	5.55	1.30	5.69	1.33	....
King	Oncorhynchus tschawytscha	April 1937	5.02	1.41	6.27	1.20	1.27
Pink	Oncorhynchus gorbuscha	April 1937	....	....	....	1.09	1.15
Silver	Oncorhynchus kisutch	Jan. 1937	5.68	1.87	6.57	1.44	1.39
Sockeye	Oncorhynchus nerka	Sept. 1937	....	....	....	1.25	....
Shad	Alosa sapidissima	May 1936	4.54	1.09	6.45	1.22	1.17
Squeteague or "sea trout"	Cynoscion regalis	June 1937	5.90	1.42	6.78	1.01	....
Tuna:							
Albacore	Germo alalunga	Nov. 1937	....	....	....	1.18	....
Bluefin	Thunnus saliens	Oct. 1937	....	....	....	1.25	....
Bonito	Sarda chiliensis	Sept. 1937	....	....	....	1.19	....
Skipjack	Euthynnus pelayms	Dec. 1937	....	....	....	1.16	....
	Shellfish and Crustacea						
Clam, hard	Venus mercenaria	Sept. 1936	5.27	1.45	5.40	1.19	....
Crab, blue	Callinectes sapidus	Nov. 1936	7.61	1.51	6.38	1.11	....
Oyster	Ostrea virginica	Oct. 1936	5.71	1.79	5.24	1.67	....
Shrimp	Peneus brasiliensis	June 1936	7.50	1.61	7.35	0.96	1.25

[a] Cystine determinations were conducted by Mr. H. C. Harris, Graduate Student Assistant, in the Bureau's College Park Technological Laboratory, College Park, Maryland.

ton mackerel, sea herring, and cod. The proteins of oyster, halibut, silver salmon, Spanish mackerel, and Boston mackerel yield satisfactory amounts of tryptophane. The cystine content does not vary to any great degree, ranging from halibut protein with 1.45 per cent of this amino acid to 1.15 per cent for the protein of croaker and pink salmon.

In table 2 are shown the arginine, histidine, lysine, tryptophane, and cystine content of casein, beef round, and egg albumin. The protein of milk, which is largely casein, is considered to be of very satisfactory nutritional value. Other animal proteins, such as those of meat and eggs, are also considered as being of good quality. Comparing the analytical results in table 2 with those in table 1, it will be seen that the proteins of fish, shellfish, and crustacea compare very favorably with casein, beef, and egg albumin in the content of the five amino acids studied.

TABLE 2

Percentage of Arginine, Histidine, Lysine, Tryptophane, and Cystine in the Proteins of Casein, Beef Round, and Egg Albumin

(From various sources)

Protein	Arginine	Histidine	Lysine	Tryptophane	Cystine
Casein	5.2	2.6	7.6	2.2	0.3
Beef round	7.5	1.8	7.6	0.9	1.3
Egg albumin	6.0	2.3	3.8	1.3	0.9

Certain essential amino acids must not only be present in a protein; they must be present in such a way as to be available for assimilation. Some proteins may be almost wholly undigestible, in which case the amino acids are not available. Other proteins that are for the most part digestible may be poor sources of certain amino acids so far as nutritive value is concerned, since these amino acids may be present in the protein molecule in such a way as to be unavailable for assimilation. The nutritive value, therefore, does not depend wholly upon the amino acid composition of the protein. Citations from the literature, and data from studies made in this Bureau on the nutritive value of some proteins from fishery products (Lanham and Lemon, 1938), indicate that fish proteins have been found to be of high nutritive value and very digestible.

Together with the ample supply of certain essential amino acids, minerals, and vitamins found in fish, shellfish, and crustacea, and the high nutritive quality and digestibility of the proteins, this group of food products may be classed among the more desirable. Fishery products should be used freely as a main source of protein or as a supplementary protein to balance the deficiencies of less nutritive proteins which may be included in the average dietary.

SUMMARY

1. The arginine, histidine, and lysine content of the proteins from the edible portions of 20 species of fish, shellfish, and crustacea was determined; tryptophane was determined in 28 species, and cystine in 13 species.
2. With respect to nutritive value, the content of the five amino acids studied indicates that the proteins of fish, shellfish, and crustacea compare very favorably with those of casein, beef, and egg albumin.
3. Fishery products are to be recommended as a main source of protein or as a supplementary protein to balance the deficiencies of less nutritive proteins.

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THE VALUE OF ULTRAVIOLET LIGHT AND OF CERTAIN CHEMICAL COMPOUNDS AS BACTERICIDAL AGENTS IN SEA-FISH PRESERVATION

By H. L. A. Tarr

Attempts to improve the keeping quality of round (dressed) sea fish by icing them with ices containing incorporated bactericidal compounds, or by treating them with solutions designed to kill the contaminating bacteria before they gain access to the fish, have never proved very successful: the germicide has either been too inactive or has caused an undesirable appearance in the treated fish.[1] Therefore, in recent years, more attention has been given to the treatment of fillets, steaks, or split fish. In these, more intimate contact is afforded between the germicidal agent and the putrefactive microörganisms.

In recent years, work at the Low Temperature Station, Cambridge, and the Westinghouse laboratories has indicated that ultraviolet light may prove of value in retarding the bacterial spoilage and molding of meats and certain other foods. Experiments were therefore begun at the Pacific Fisheries Experimental Station at Prince Rupert, B. C., in order to ascertain whether the bacterial spoilage of fish might be delayed by treatment with ultraviolet light. In these experiments, recently developed economical ultraviolet lamps were used in a specially constructed cabinet, the fillets being hung up and exposed to the rays for various lengths of time. The results of preliminary work have already been published in abbreviated form.[2] It has been found that the initial bacterial contamination can be considerably decreased, especially when fillets treated are freshly cut and the bacteria are largely on their surfaces. However, the action is purely superficial, bacteria multiplying rapidly in the nonexposed portions of the fillets during prolonged irradiation. Ultraviolet light forms a convenient means of rendering brines or pickles practically sterile bacteriologically.[3]

The literature dealing with the preservation of fish by chemical agents is extensive, and will not be considered in detail here as it has already been reviewed.[4] Since about 1870, boric acid has been used in the salting and pickling of fish, especially to prevent red discoloration, but it has to some degree been superseded by sodium benzoate. Other compounds the use of which is referred to in certain early publications dealing with fish preservation include carbon disulphide, chloroform, ether, glycerine, formic acid, saltpeter and alum, sodium sulphite, carbolic acid, aluminum acetate, salicylic acid, sulphurous acid, sodium fluoride, etc. During recent years the problem of fresh-fillet preservation seems to have been taken up with renewed vigor. Storage in atmospheres containing high concentrations of carbon dioxide, or immersing the fish in solutions containing harmless organic acids, hydrochloric acid, hypochlorite, or hydrogen peroxide have all been investigated.

In 1938 an investigation into the chemical preservation of fillets was begun at this Station in connection with lightly smoked fish,[5] and has more recently been extended to cover fresh fillets.[6] The results obtained in these experiments will be briefly discussed.

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[1] Tarr and Bailey, Jour. Fish. Res. Bd. Canada, 1939 (in press); Tarr and Sunderland, Jour. Fish. Res. Bd. Canada (MS).

[2] Tarr, Young, and Sunderland, Fish. Res. Bd. Canada, Prog. Rept. Pacific, 38:3–6, 1938.

[3] Young, Tarr, and Sunderland, Fish. Res. Bd. Canada, Prog. Rept. Pacific, 39:16–18, 1939.

[4] Tarr and Sunderland, Jour. Fish. Res. Bd., Canada (MS).

[5] Tarr and Sunderland, Fish. Res. Bd. Canada, Prog. Rept. Pacific, 37:7–11, 1938.

[6] Tarr and Sunderland, Fish. Res. Bd. Canada, Prog. Rept. Pacific, 39:13–16, 1939; *idem, ibid.,* 40:14–17, 1939; *idem* (MS).

Small experimental fillets of Pacific Coast fish including halibut, flounder, gray cod, ling cod, black cod, and red cod were used. The technique employed consisted of immersing the fillets for one hour at about 20° C. in 2-per cent sodium chloride brines containing preservative in concentrations of from 0.02 to 1 per cent, depending on the nature of the chemical employed. The treated fillets were subsequently stored in sterilized glass containers at approximately 1.5° C., together with fillets exposed to brine without added preservative, until the latter became stale. The fillets were then examined, the numbers of viable bacteria present being determined, and organoleptic tests being made.

Hydrogen peroxide (0.1 per cent), hydrochloric acid (0.07 per cent), and boric acid (0.1 per cent) were not particularly effective in the concentrations employed. Sulphur dioxide (0.1 per cent) was fairly effective, but caused the treated fish to assume a very unpleasant odor and taste, probably because it reacted with the oils in the fish. Both sulphur dioxide and hydrochloric acid caused the treated fillets to become rough and whitish in appearance. Chloroform (0.7 per cent) proved to be very active, and it has the advantage that it evaporates on storage. Both boric acid (0.1 per cent) and para hydroxybenzoic acid ethyl ester (0.09 per cent) prevented deterioration slightly, but neither was as effective as free benzoic acid (0.1 per cent) or sodium benzoate (0.1 to 1.0 per cent). Benzoic acid was more active than sodium benzoate when used in the same concentration, but the free acid has the disadvantage that it produces a slight roughness on the surface of treated fillets. Since the preservative differences were not marked, and since free benzoic acid is only slightly soluble in water and is neutralized when it comes in contact with the fish muscle, it would appear most desirable to use the sodium salt.

During these studies on different preservatives it was found that potassium and sodium nitrites produced a marked decrease in the rate of bacterial putrefaction of stored fillets. In fact, nitrites were shown to possess a much stronger preservative action than the other substances studied, when employed in similar concentrations. This finding naturally led to a more detailed study of the protective action of nitrites, and to the evolution of a simple process of treating fillets on a fairly large scale. This method depends on two facts: first, on the selective action on the normal bacterial flora of fresh fillets caused by immersing them in strong sodium-chloride brines; and secondly, on the inhibitive action of nitrites on the remaining salt-tolerant organisms. So far, the treatment which has given optimum keeping quality to fresh fillets is that of immersing them for five minutes in ice-cold (0–2° C.) 60° salinometer brine (15 per cent sodium chloride by weight) containing about 0.4 to 0.5 per cent sodium nitrite. The iced brine "dip" alone causes a very marked increase in the keeping quality of fresh fillets, improves their appearance by giving them a smooth, shiny surface, and at the same time causes them to absorb a sufficient amount of salt to make them more palatable on cooking. The addition of sodium nitrite to such brines causes an even greater increase in keeping quality. Experiments with pure cultures of certain bacteria associated with spoiling fish muscle have shown that sodium nitrite possesses a marked bacteriostatic action.

The use of sodium nitrite in cured meats (including fish) in concentrations not exceeding 200 parts per million in the finished product is permitted by law on this continent; this concentration strongly enhances the keeping quality of both fresh and lightly smoked fish fillets. Experiments have also shown that nitrites cause an intensification in color of salmon muscle, especially after smoking, freezing, canning, or cooking. Whether this is due to the occurrence of haematin derivatives, such as myoglobin, in fish muscle, and to their interaction with nitrites to form nitrosohaemoglobin, as occurs in cured meats, is as yet obscure.

It is to be hoped that the information given in this paper will prove useful to those whose concern it is to see that fish reaches the consuming public in a truly fresh state, and not as an inedible semidecomposed product. The whole problem of fresh-fish preservation is as yet in its infancy. It includes not only the preservation of strictly fresh fish, but of such fish before freezing and after thawing until it reaches the ultimate consumer. Therefore any advance which is made, however trivial, must not be disregarded.

THE USE OF CERTAIN INTRINSIC QUALITY CHARACTERISTICS IN GRADING BRITISH COLUMBIA CANNED SOCKEYE SALMON

By F. Charnley

The problem of setting up a scientifically sound plan for grading salmon is threefold in character in that it involves: (1) the selection of one or more quality characteristics upon which the grading is to be based; (2) the development of rapid and reasonably accurate means of measuring the quality characteristic or characteristics employed in the grading; and (3) the application of statistical methods to the results of the tests developed under (2), that is, to the measurements of the quality characteristics employed in the grading.

Commercially, the problem listed under (1) has been reduced to the comparatively simple problem of choosing one or more quality characteristics from among a relatively few well-known characteristics. Similarly, except with respect to freshness, rapid and reasonably accurate methods of measuring the desired quality characteristics are now available. The task of setting up a scientifically sound plan for grading canned salmon is thus concerned largely with the problem listed under (3).

In practice, however, it is found that difficulties arise in this last problem, owing to the fact that the nature of the quality characteristics imposes restrictions on the choice of a grading plan. Thus a study of the various quality characteristics of canned salmon shows that they are, in general, of two types, namely, those of a purely adventitious character resulting from processing, as, for example, vacuum, and those of an intrinsic character depending upon the quality of the salmon *per se,* such as firmness, red and yellow colors of the flesh, and free oil content. These latter characteristics differ from the first class of characteristics by the fact that they are all affected by seasonal variations in average quality and, as a consequence, are much more conveniently dealt with in any plan for grading canned salmon when considered separately.

The object of the present paper is to consider a simple practical method of grading based on this second type of quality characteristic. In what follows we shall therefore assume that the sample has been passed so far as freshness and other characteristics belonging to the first class are concerned, and that the grading is to be based on the characteristics firmness, red and yellow colors of the flesh, and free oil content (average of 12 cans).

By virtue of two further properties of the latter characteristics it will suffice, then, for the purpose of setting up a plan for grading canned sockeye salmon, to consider a single normally disturbed characteristic of constant standard deviation. These two additional properties are, first, that the standard deviations of these characteristics around the lines of trend (means) are, within sampling fluctuations, constant during the season, and second, the characteristics are all normally distributed around the lines of trend (Bolton, Charnley, and Goard, unpublished data).

Under these conditions the distribution of the average (arithmetic mean) of a given sample, say 12, will therefore be normal. Also, as the average quality of the characteristic changes, the distribution of the average of samples of 12 will merely move horizontally to the right or left, as shown in figure 1. In the latter figure, X_c is the average of the distribution of averages of samples drawn from quality X_c. Similarly, X_p is the average of the distribution of averages of samples drawn from quality X_p. If X_c and X_p are each three standard deviations from X_L, then under the above-described conditions of sampling the probability of drawing a sample of 12 from the quality X_c having an average equal to or greater than X_L is 0.00135.

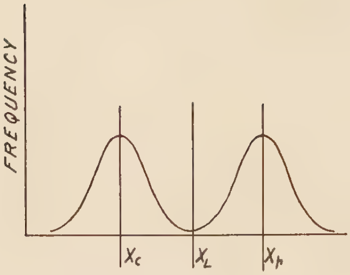

Fig. 1. Diagram illustrating producer's and consumer's risks and effective levels corresponding to a given sample size and a given acceptance limit.

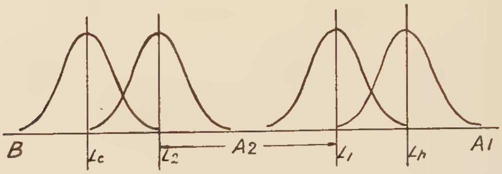

Fig. 2. Graphical illustration of regions or intervals of uncertainty bounding any given grade of quality.

Consequently, if X_L is the acceptance limit for average of 12, that is, if the examiner rejects the parcel whenever the average quality in samples of 12 is X_L or lower, then owing to sampling fluctuations the consumer will be called upon to accept a certain proportion of parcels of lower average quality than X_L. The lowest average quality of such parcels, and the proportion of such parcels, that he will be required to accept, however, are accurately specified by the average X_c and the probability $P_c = 0.00135$, that is, by the consumer's effective level and consumer's risk. In this instance, the consumer would, in the long run, be asked to accept, only out of every 10,000 of the parcels submitted for examination about 13, the average quality of which was X_c or lower.

Similar reasoning evidently applies to the producer's risk and effective level. If, for example, the producer wishes to insure that, in the long run, less than about 13 out of every 10,000 of the parcels he submits for examination will be rejected, then he will need to keep the quality of his product at the level X_p or higher under the preceding conditions of sampling and inspection.

From the preceding definitions of producer's and consumer's risks, it is evident that the limits bounding any given grade of quality X_1 to X_2 are in reality intervals or regions of uncertainty. In grading grade A canned salmon into two subgrades or classes, for example, the limits defining one of these subgrades, say A2, would be somewhat as shown in figure 2, under the above-described conditions of sampling and inspection. If the limits of grade A2 quality are L_1 and L_2 and the salmon canner wishes to ensure that certain parcels of his pack will pass as grade A1, then he would need to see that the quality of these parcels was equal to or greater than L_p under the above-described conditions of sampling. Similarly, the consumer would be called upon to accept as grade A2 quality a certain proportion of parcels that were actually of grade B quality, but the lower limit of quality of such parcels would be L_c, corresponding to a sample of size 12 and the above-described consumer's risk.

The fineness of the grading attainable is evidently dependent on the size of sample taken for examination. Owing to the effect of natural causes, the total range of grade A quality is fixed. Hence, if the sample size n is fixed, it may happen that it is not possible to classify grade A salmon into more than, say, two subclasses or grades. The reason for this will be readily apparent on considering figures 3 and 4. Figure 3 illustrates the situation resulting from narrowing the interval of grade A2 quality so that the limits L_1 and L_2 are 6S (6 standard deviations) apart. In figure 4 the interval corresponding to A2 quality has been reduced to one-half this distance.

There is always, of course, an overlapping in adjacent grades. By bringing the limits L_1 and L_2 closer together, as in figures 3 and 4, this overlapping is

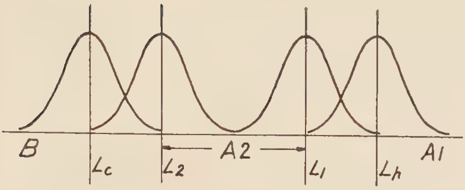

Fig. 3. Grading plan in which grading intervals are 6 standard deviations in length.

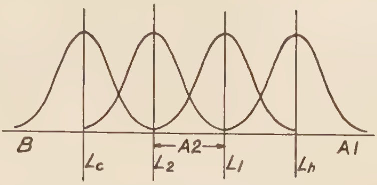

Fig. 4. Grading plan in which grading intervals are only 3 standard deviations in length.

considerably increased. In figure 3, however, there is still good segregation into distinct grades in the sense that it is possible to specify values of average quality, such as L_c and L_p, which do not appear simultaneously in the adjacent grades greater than the proportion of times given by the consumer's or producer's risk, providing the grades in which these values of average quality appear have intervals that are not less than 6S, that is, providing that each of the intervals of the grades A1 and B in figure 3, for example, are not less than 6S. For figure 4 it is not possible to specify such average qualities, if the grading intervals are all equal. Furthermore, in figure 4 there is overlapping in three adjacent grades, and if the grading interval A2 is further reduced, the proportion of times that the quality L_1 will be graded B under these circumstances will steadily become greater than 0.00135.

The purpose of grading, however, is to separate the good from the bad or the superior from the inferior. A grading plan that occasionally assigns the same quality to three adjacent grades cannot be said to fulfill this function satisfactorily. Hence, it would appear that the grading plan illustrated in figure 4 represents the minimum requirements for practical grading purposes. For the latter purpose, the distance between the acceptance limits L_1 and L_2 should be at least 3S, and in a really satisfactory grading plan this distance should be equal to or greater than 6S.

Example 1.—As an illustration of the practical problem of setting up a grading plan for a single quality characteristic we may consider the problem of grading canned sockeye salmon on the basis of the red color of the flesh. For this purpose we require estimates of the total range in average quality in this characteristic during the season, together with the standard deviation around the line of trend (means). Table 1 shows that for the 1938 season, for example, the range in average red color for this species was from about 4.0 to 6.74 Lovibond units, while the standard deviation around the line of means was approximately 0.710 unit. If, therefore, the examiner wishes to set up two equal grades of quality on the basis of this characteristic, and wishes further to insure that the intervals corresponding to the two grades shall not be less than 6S, he would need to inspect a sample size n fulfilling the condition

$$6.74 - 4.0 = \frac{12 \times 0.710}{\sqrt{n}},$$

that is, a sample of size $n = 10$ approximately. If the examiner wished to classify the parcels submitted for examination into three equal grades, then by means of an equation similar to the preceding he would find that he should inspect a sample of size $n = 22$ approximately. If the examiner employs an interval between two adjacent grades less than 6S, the sample sizes will, of course, be respectively less than these, but there will be an increasing amount of overlapping in three adjacent grades.

TABLE 1

VALUES OF STATISTICS CALCULATED FROM 1938—½-LB. FLAT SOCKEYE DATA DERIVED FROM SOUTHERN (FRASER RIVER) AREA

Characteristic	Averages			Standard deviations
	Modal interval	Max.	Min.	
Red color	6.46	6.74	4.00	0.710 units
Yellow color	4.26	4.72	3.29	0.567 units
Firmness	11.86	14.02	7.66	2.16 units
Free oil (average of 12 cans)	3.52	6.58	0.62	1.233 c.c.

The foregoing considerations, it will be observed, are only properly applicable to a single normally distributed characteristic of constant standard deviation. In the present instance, however, these considerations are also applicable to an index of quality combining the individual quality characteristics, providing care is taken, as with respect to a single characteristic, to inspect individual codes where the latter have been packed in distinctly different intervals during the season, that is, where there are appreciable differences in average quality among the various codes.

To combine the individual quality characteristics into a suitable index of quality we need only note that the sum of any number of normally distributed characteristics is normally distributed with a variance equal to the sum of the individual variances. Thus if a number of variates X_1, X_2, . . ., are normally distributed, then the corresponding characteristic functions of the individual variates are

$$e^{\frac{\sigma_1^2t^2}{2}}, e^{-\frac{\sigma_2^2t^2}{2}}, \dots$$

and hence the characteristic function for

$$Z = x_1 + x_2 + \dots \text{ is } e^{-(\sigma_1^2+\sigma_2^2+\dots)\,t^2_2}$$

From the properties of characteristic functions it therefore follows that

$$\sigma^2 = \sigma_1^2 + \sigma_2^2 + \dots$$

If two individual characteristics are correlated, the characteristic function of their sum $Z = X_1 + X_2$ is

$$e^{\frac{\sigma_1^2u^2 + 2r\sigma_1\sigma_2uv + \sigma_2^2v^2}{2}}$$

and consequently the variance of their sum Z is $\sigma^2 = \sigma_1^2 + 2\nu\sigma_1\sigma_2 + \sigma_2^2$. Similarly, by an extension of the reasoning it may be shown that the variance of the sum of three normally correlated variates is given by the equation

$$\sigma^2 = \sigma_1^2 + \sigma_2^2 + \sigma_3^2 + 2r_{12}\sigma_1\sigma_2 + 2r_{13}\sigma_1\sigma_3 + 2r_{23}\sigma_2\sigma_3$$

In combining the four intrinsic quality characteristics of canned sockeye salmon mentioned above, we may evidently set up a number of possible grading plans for this species according as we combine two, three, or all four characteristics to give an index of quality. Reference to table 2, however, shows that certain of these characteristics are much more suitable for grading purposes than others. On comparing ranges in average quality with corresponding standard deviations of samples of 12 of the various characteristics (table 2) we find that average free oil is a much less sensitive characteristic than the others. For this characteristic the range in average quality is only about 5 standard deviations, while for average red color, for example, the range is almost 14 standard deviations. In combining these characteristics to give an index of quality it may therefore be more satisfactory for some purposes to base the grading on only two of the characteristics, such as the more sensitive characteristics red color and firmness.

TABLE 2

RANGES AND STANDARD DEVIATIONS OF AVERAGES OF 12 CALCULATED FROM THE DATA OF TABLE 1

Characteristic	Standard deviation of average of 12	Range
Red color	0.205	2.74
Yellow color	0.164	1.43
Firmness	0.624	6.36
Free oil content	1.233	5.96

As illustrations of possible indices of quality for grading one-half flat canned sockeye salmon it is therefore of interest to consider briefly the following.

Example 2.—Index based on red color and firmness. Sample size, 12. From the values of the standard deviations listed in table 2 it follows that the standard deviation of the sum of the two varieties or averages is

$$s = \sqrt{0.205^2 + 0.624^2} = 0.6568.$$

Also, since the maximal values of the averages occur in approximately the same time interval, the upper limit of the sum of the averages may be taken as $L_2 = 6.74 + 14.02 = 20.76$, and for similar reasons the lower limit of the sum of the averages is $L_1 = 4.00 + 7.66 = 11.66$. If the grading intervals are equal and each equal to 6S in value, we therefore have $12 \times 0.6568 = 7.88$, while the total range is $20.76 - 11.66 = 9.10$. On the basis of a sample of size 12 the sum of the averages of these two characteristics would thus readily allow grading into two equal grades. Only a small percentage of British Columbia canned sockeye salmon is annually graded B, so that the sum of the averages of 12 of these two characteristics would readily permit further classification of the present grade A salmon into two subgrades or classes.

Example 3.—Index based on the three characteristics, red color, firmness, and free oil content. Sample size, 12. In this example $S = 1.396$, while L_1 and L_2 are respectively 12.28 and 27.34. Comparing the ranges we find $12 \times 1.396 = 16.75$ and $27.34 - 12.28 = 15.06$. This index is therefore not as sensitive as the previous one and would barely fulfill the requirements of a good grading plan.

Example 4.—Index based on the four characteristics, red color, yellow color, firmness, and free oil content. Sample size, 12. Here the characteristics red and yellow colors of the flesh are correlated with an estimated correlation of 0.70. The standard deviation of the sum of the averages is therefore

$$\begin{aligned} s &= (0.205^2 + 0.624^2 + 0.164^2 + 1.233^2 + 2 \times 0.70 \times 0.204 \times 0.164)^{1/2} \\ &= 1.423. \end{aligned}$$

On comparing ranges, we find 12 × 1.423 = 17.08 and 32.06 — 15.57 = 16.49. The index would therefore approximately allow grading into two equal subgrades on the basis of a sample of 12 and the above-described equal grading ranges.

The foregoing indices, it will be observed, are unweighted in the sense that no attempt has been made to alter the relative effects of the component characteristics. Where weightings are desired, however, it is a simple matter to apply these arithmetically, since if the mean is weighted by the factor k, the resulting standard deviation will be k times the original standard deviation. A desirable procedure to follow in weighting the above-described characteristics of canned sockeye salmon would seem to be to base the weight on the properties of the component characteristics. In the concluding example the weighting factors suggested are the ratios of the averages of the component characteristics in the modal interval.

Example 5.—Weighted index based on the characteristics red color, firmness, and free oil content. Sample size, 12. If the average firmness in the modal interval is taken as standard, the factors required in weighting red color and free oil will be respectively, 11.86/6.46 = 1.836 and 11.86/3.52 = 3.369. The corresponding standard deviations are therefore 1.304 and 4.154, respectively, and hence the standard deviations of the averages of twelve are 0.3764 and 4.154. The standard deviation of the weighted index is thus 4.217. Since the range covered by this index is 48.56 — 17.09 = 31.47 and 12 × 4.217 = 50.60, the weights in this example have increased the relative effect of the free oil content.

TRIMETHYLAMINEOXIDEASE: A BACTERIAL ENZYME CATALYZING THE REDUCTION OF TRIMETHYLAMINE OXIDE

By H. L. A. Tarr

Trimethylamine oxide was isolated from sea fish by Suwa,[1] and Poller and Linneweh[2] showed that it was reduced to the corresponding amine during bacterial spoilage of fish tissues. Recent work by Beatty[3] has proved that it is practically certain that at least 94 per cent of the trimethylamine formed during the bacterial putrefaction of codfish muscle press juice arises from the trimethylamine oxide present therein, and not from other possible precursors. It has also been shown that sterile fish muscle press juice[4] and fish muscle[5] do not reduce the oxide, and that by no means all the types of bacteria concerned in fish spoilage form trimethylamine.[6] The amount of trimethylamine oxide present in the muscle of different sea fish varies greatly,[7] there is by no means a uniform relationship between the viable bacterial population and the amount of trimethylamine in spoiling fish muscle,[8] and therefore it is as yet uncertain whether the simple determination of the amount of trimethylamine in such a substance will form a reliable index of its state of freshness.

During investigations concerned with fish preservation[9] the necessity of employing some defined index of spoilage arose, and in addition to the usual organoleptic tests, both viable bacterial counts and trimethylamine content of the spoiling fish muscle were studied. It was found that, for reasons already cited, the trimethylamine test did not yield entirely consistent results. This finding led to a study of the relation between trimethylamine formation and bacterial flora of spoiling fish muscle, the following results being obtained.

Only three (two species of micrococci and one achromobacter) of thirty microörganisms (15 micrococci, 4 flavobacteria, 6 achromobacteria and 5 yeasts) isolated at random from seven samples of fresh or lightly smoked sea fish in various stages of decomposition formed trimethylamine when cultivated in an aqueous extract of halibut muscle. The reduction of an 0.02M solution of trimethylamine oxide was found to be quantitative and practically linear when washed suspensions of the cells of these three organisms were incubated anaerobically in Thunberg tubes at pH 7.0, halibut muscle extract being used as oxidizable substrate. Under these conditions the remaining twenty-seven cultures did not reduce trimethylamine oxide appreciably. Further experiments showed that all of a large number of dehydrogenase enzymes of one or other of two of the trimethylamine-forming bacteria studied, including the lactate, glucose, fructose, hexosemonophosphate, hexosemonophosphoric acid, acetate, formate, and succinate systems were capable of accelerating the endogenous reduction of trimethylamine oxide in the presence of washed-cell suspensions of these organisms. By use of the oxidation-reduction indicator technique employed by Green, Stickland, and Tarr[10] in their study of "Carrier-linked reactions," it was found that the reduction of trimethylamine oxide depended on its activation by the trimethylamine-forming organisms. The existence of a specific trimethylamine oxide activating enzyme was therefore postulated, and it has been tentatively named "trimethylamineoxidease," or, briefly, "triamineoxidease." This enzyme appears to activate its substrate irreversibly, as occurs with the "nitratase" enzyme of bacteria,[11] rendering it capable of reduction by various dehydrogenase systems of lower potential level, but not reoxidation by molecular oxygen. The oxidation-reduction potential of the enzyme-substrate complex (trimethylamine oxide–triamineoxidease) is somewhat more positive than that of methylene blue–leuco methylene blue.

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[1] Suwa, Arch. f. Physiol, 128:421, 1908, and 129:231, 1909.

[2] Poller and Linneweh, Ber., 59:1362, 1926.

[3] Beatty, Jour. Fish. Res. Bd. Canada, 4:63, 1938.

[4] Beatty and Gibbons, Jour. Fish. Res. Bd. Canada, 3:77, 1936.

[5] Brocklesby and Riddell, Biol. Bd. Canada, Prog. Rept. Pacific, 33:17, 1937.

[6] Tarr, Nature, 142:1078, 1938; *idem,* Chem. and Ind., 58:253, 1939; *idem,* Jour. Fish. Res. Bd. Canada (in press); Watson, Jour. Fish. Res. Bd. Canada, 4:252 and 267, 1939.

[7] Beatty, Jour. Fish. Res. Bd. Canada, 4:229, 1939.

[8] See note 6 above.

[9] See note 6 above; also Tarr, Jour. Fish. Res. Bd. Canada (in press); Tarr and Sunderland, Fish. Res. Bd. Canada, Prog. Rept. Pacific, 37:7, 1939; Proc. 5th Pac. Sci. Cong. (paper presented at Congress).

The substrate specificity of triamineoxidease is now being investigated by ascertaining whether trimethylamine-forming bacteria are capable of forming this volatile base from organic bases such as ergothioneine, choline, acetyl choline, betaine, etc., all of which possess a nitrogen with three methyl groups attached. It is of interest to note that it has always been stated that the trimethylamine sometimes occurring in tainted butter arises from the choline which is split from lecithin. Three strains of bacteria associated with the production of surface taint of butter which were kindly given me by Dr. Eagles of the University of British Columbia formed trimethylamine from trimethylamine oxide, but not from choline. Further research along these lines is indicated.

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[10] Green, Stickland, and Tarr, Biochem. Jour., 28:1812, 1934.

[11] L. H. Stickland, Biochem. Jour. 25:1543, 1931.

COMPARATIVE STUDIES OF THE OVERHEAD-TANK AND END-TANK METHODS OF COOLING REFRIGERATOR CARS

By O. C. Young

In considering the basic problems of the comparatively new industry of the production and distribution of quick-frozen perishable foods, it is now recognized that the actual procedure of quick freezing is by itself of comparatively little practical importance. It is merely one of the essential steps in the process of distributing perishable foods from the producer to the consumer more efficaciously. Among the more important steps is the storage of these perishables, and under this heading comes transportation.

The care of perishables in transit has received attention from our Canadian railway companies, but until more recent years their efforts were directed more toward increased efficiency and ease of servicing their equipment than toward the improvement in quality of the commodities handled. Their engineers recognized that the logical place to apply refrigeration in refrigerator cars is just under the ceiling; therefore, to increase the efficiency and to induce more uniform temperature distributions in the car the Canadian Pacific Railways built an experimental car in 1912 after the Moore Type, whereby cooling was effected by brine pipes along the ceiling. This car was followed in 1918 by one of the A.B.C. type, which also contained brine pipes arranged along the ceiling, but they were grouped in fours connected to a header through which the brine flow was controlled somewhat by means of flap valves. Neither car, however, showed sufficient promise to warrant general adoption.

In spite of the unsuccessful attempts at overhead cooling in America, E. A. Griffiths and his associates in the Union of South Africa experimented with roof tanks in insulated railway cars and, after overcoming many difficulties, by 1930 evolved a roof-tank car that showed so many advantages over the standard end-tank car that it was adopted in that country as a practical unit.

Since 1929, when increased knowledge concerning the freezing and cold storage of perishables gave such an impetus to the frozen foods industry, the need of improved transport facilities for this type of commodity in Canada became acute, particularly for handling frozen fish. In 1933, therefore, the Biological Board of Canada (now the Fisheries Research Board of Canada) undertook some experiments to learn more about the methods of cooling refrigerator cars, particularly the overhead method of cooling, since the principle was fundamentally sound and was successfully applied in Africa.

The studies were carried out at the Board's Pacific Fisheries Experimental Station, at Prince Rupert, B. C.,[1] and were conducted with an insulated box constructed to simulate a miniature refrigerator car. The box was fitted with both roof tanks and end tanks, hatches, baffles, doors, and drains, much as would be found in a standard car. In order to compare the effects of different forms of insulation *in situ*, the box was made in a "knockdown" manner so that the insulation could be changed without otherwise altering the construction. Furthermore, two systems of drainage were provided for the roof tanks: one system consisting of ordinary down pipes to conduct the waste brine away as soon as it was formed, and the other consisting of fabric incorporated in the sides of the car in waterproof compartments outside the insulation. By use of the latter system the cold brine in being conducted through the fabric in the walls reduced the temperature of the walls somewhat and thus caused a saving in refrigeration.

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[1] O. C. Young, Prog. Rept. (Pacific) of the Biological Board of Canada, No. 17, p. 13, 1933.

This box was placed in a room in which the temperature was controlled, but unfortunately the size of the room did not permit constructing the box of dimensions strictly proportional to those of the standard refrigerator car. It was desirable to have the box high enough to permit a workman to crawl inside, and therefore its length was made somewhat shorter than strict proportionality demanded, so that it could be accommodated in the available room. The results were corrected where necessary to reduce them to standard proportions.

Temperature measurements were made by means of both automatic recording and hand-operated electrical resistance thermometers and by means of thermocouples. Temperatures were taken at numerous places inside and outside the box to supply reliable data for determining mean temperatures, temperature distributions, and variations in the temperatures during the cycles of performance between replenishments of the cooling mixtures in the tanks.

TABLE 1

Data Relating to Different Methods of Cooling

Method of cooling	Cooling medium	Mean temperature in car (deg. F.)	Difference in temperature between warm and cold points (deg. F.)	Maximum daily temperature fluctuation (deg. F.)	Weight of cooling mixture used per day (lb.)
Roof tanks	Ice only	36.3	0.7	....	48.1
Roof tanks	Ice + 5-per cent salt	32.2	0.8	2.2	54.8
Roof tanks	Ice + 10-per cent salt	27.8	0.8	3.0	73.8
Roof tanks	Ice + 15-per cent salt	23.5	1.4	3.5	94.2
Roof tanks	Ice + 20-per cent salt	15.0	1.4	3.7	133.7
End tanks	Ice only	37.5	3.6	....	43.3
End tanks	Ice + 5-per cent salt	33.4	4.0	4.5	57.0
End tanks	Ice + 10-per cent salt	27.9	4.8	4.7	77.5
End tanks	Ice + 15-per cent salt	23.5	5.7	4.8	95.1
End tanks	Ice + 20-per cent salt	16.3	7.6	5.0	133.0

The cooling media of ice and salt in the proportions used were mixed in a room held at minus 10° F. or lower, so that the mixture would always be dry when placed in the tanks and would therefore supply an easily determinable quantity of refrigeration per pound of mixture. The amount of mixture melted per day was determined by weighing the resultant water or brine, and specific gravity determinations of this brine served as checks on the proportions of salt used in the cooling mixture.

The data given in table 1 were obtained with an external temperature of 62° F. and are the means of from 7 to 12 days' continuous runs. From these results the mean temperatures, the temperature distribution, and the relation between temperature obtainable for a given salt concentration in the cooling mixture may be compared for the two methods of cooling. Also the weights of cooling mixture used per day may be compared.

It will be noticed that the relation between salt concentration and mean temperature in the box was quite similar for both systems of cooling, and that the amount of cooling mixture required each day was not significantly different. This was to be expected, since only a definite amount of cooling may be effected for a given quantity of cooling mixture, and the economy derived from overhead cooling appears at the latter end of trips when reicing is discontinued so as to complete the journey with very little ice in the tanks. With the end-tank system, however, in order to keep temperatures down in the upper central regions of the car, the tanks must be kept practically full of mixture and this is all wasted after the car is unloaded.

The main advantage of the overhead system of cooling is shown by the extremely uniform temperatures found throughout the interior of the box, irrespective of the outside temperature. Our experiments showed that with a 20-per cent salt mixture, by means of which the mean temperature in the box was held at approximately 15° F., the maximum difference between the warmest and coldest points was less than 1½° F., whereas with the end tanks in operation this difference was 7.6° F. while the outside temperature was maintained at 62° F. On raising the outside temperature to 77° F., however, although the effect was negligible with the roof tanks operating, the effect of the end tanks was to increase the difference between the warmest and coldest points to 9.0° F. Where maintaining quality standards in frozen perishables is a consideration, uniformity of temperature in the transport vehicle is of primary importance; and it was for this reason that the improvements shown with the overhead tanks were felt to be worth while exploiting.

TABLE 2

Data Relating to Use of Two Kinds of Insulation

Insulation used	Weight required for 3-inch thickness (lb.)	Cooling mixture required per day (lb.)	Thermal conductivity of composite wall (BTU per sq. ft. per hr. per deg. F.)	Conductivity of insulation only (BTU per inch per sq. ft. per hr. per deg. F.)
Hair felt............	293	95.1	0.064	0.25
Aluminum foil plus wire hangers......	10	106.0	0.078	0.31

After completing the comparative study of the two methods of cooling the experimental model, the insulation in the walls, floor, and ceiling was changed. In the first experiments the insulation consisted of three 1-inch layers of hair felt. In the second experiments this was changed to 8 sheets of crumpled aluminum foil applied according to the instructions of the Aluminum Company of Canada, which supplied the foil for the tests. The results of these tests, given in table 2, show the great saving in weight resulting from the use of aluminum foil. By correcting these data to apply to a standard size, it is found that it requires approximately 2½ tons of hair felt to insulate the standard refrigerator car with 3 inches of hair felt, whereas only 200 pounds of crumpled aluminum foil and wire hangers would be required. This great saving in weight, however, is offset by a somewhat higher conductivity for a given thickness, as shown by the 11½-per cent more cooling mixture required per day to induce similar conditions in the car when using the aluminum foil as the insulation. Apart from weight and conductivity considerations, aluminum foil has still to prove its value in durability. The foil is extremely perishable in the presence of chlorides; therefore, unless it is amply protected, it will tarnish and disintegrate in the walls of a car. On the other hand, hair felt, too, has its drawbacks aside from its weight, since it absorbs moisture readily and then becomes a generous host for molds and bacteria. The odors resulting from infection by microörganisms are difficult to overcome and on occasions render a car useless for certain kinds of commodities. The question of the best type of insulation for refrigerator cars, therefore, is by no means settled. Experiments in progress at this Station with aluminum foil applied in a fishing boat indicate that it will retain its insulating properties at least four years, but the tests have not progressed to the stage where predictions beyond that period may be made.

The final studies made with the small model give a comparison of the two methods of drainage provided for the overhead tanks already described in connection with the construction of the box. The comparisons were made for ice alone and for a 15-per cent salt concentration in the cooling mixture, while the aluminum foil was used as insulation. The results show that the system of drainage had but a very slight effect upon the mean temperature in the car and uniformity of temperatures when using ice only, but a significant effect on the temperature distribution for a 15-per cent salt concentration. Under this latter condition the fabric drainage system reduced the maximum temperature difference between the coldest and warmest points from 1.7° F. to 0.7° F., a very great improvement. The saving in cooling mixture used per day was approximately 7.7 per cent when ice only was used, and was 10.8 per cent when a 15-per cent salt mixture was used. The respective theoretically possible savings assuming the waste brine to be warmed to within 15° F. of the outside air temperature would be 9.4 per cent and 17.2 per cent. These economies would all be somewhat higher in actual practice because the cooling mixture would not be in a dry superchilled condition as in the experiments described above, but would be wet and at the melting point of the particular concentration employed.

In order to obtain the theoretical savings and also to compare the thermal conductivities of the two forms of insulation used, it was necessary to determine the heat required to melt a pound of the salt-ice mixtures used in these experiments. This was done by a modification of the method of mixture, simply by placing the salt-ice mixture in a small copper container of predetermined thermal capacity and obtaining the heat given up to a weighed quantity of water of known temperature contained in a thermos flask. The results of these determinations were as follows.

Heat absorbed by ice only = 143.5 B.T.U. per lb. at 32°.0 F.
Heat absorbed by ice plus 5 per cent salt = 122.0 B.T.U. per lb. at 25°.2 F.
Heat absorbed by ice plus 10 per cent salt = 109.0 B.T.U. per lb. at 18°.7 F.
Heat absorbed by ice plus 15 per cent salt = 102.7 B.T.U. per lb. at 12°.2 F.
Heat absorbed by ice plus 20 per cent salt = 87.0 B.T.U. per lb. at 6°.1 F.

According to Jessup, of the Bureau of Standards, one pound of sodium chloride eutectic brine ice in changing from solid to liquid at minus 6° F. absorbs 101.5 B.T.U.,[2] whereas a 20-per cent salt-ice mixture absorbed only 87.0 B.T.U. per pound in the above-described experiments. One disadvantage of using salt-ice mixtures is readily shown, therefore, by these results, but another disadvantage not shown is the variations in temperature experienced with these mixtures. Mixing is never sufficiently thorough to give a constant melting temperature, while with eutectic ice the melting point remains fixed.

After the experiments with the experimental box were completed, it was decided that the results were sufficiently encouraging to warrant extending the studies to full sized cars. Therefore, in the winter of 1933–34, through the coöperation of the Canadian National Railways and the Prince Rupert Dry Dock, two standard type end-tank cars were obtained and one was temporarily fitted with 16 galvanized iron roof tanks. The cars were placed end to end in the heated machine shop of the Prince Rupert Dry Dock and were therefore subjected to approximately the same external temperature conditions.

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[2] R. S. Jessup, Refrigerating Engineering, 22:166, 1931,

Although these tests were made under somewhat adverse conditions, the general results supported the work done in the laboratory exceedingly well, showing the more rapid cooling obtained with the roof-tank car, the more uniform temperature distribution, and the reduction in effects of external temperature variations.[3]

Our two large Canadian railway companies became interested in these experiments and were sufficiently impressed by the results to build experimental cars. The first of these was built in 1936 by the Canadian Pacific and tested[4] with a carload of frozen fish from Vancouver to Winnipeg in July of that year, when the temperature rose above 90° F. each day during the five days required for the trip. The car performed exceedingly well, but unfortunately no control car could be used, owing to the lack of a frozen fish load. However, at Winnipeg two carloads of fresh beef were secured for shipment to Montreal, thus permitting a control for this second test.

The trip from Winnipeg to Montreal took approximately four days and during that time the end-tank or control car was reiced three times, using in all 4000 pounds of ice and 480 pounds of salt, while the roof-tank car was reiced but once, using 1600 pounds of ice and 200 pounds of salt. With this treatment it took 48 hours to reduce the temperature of the beef at the warmest point in the end-tank car to 40° F. in spite of the fact that the coldest point was uncomfortably close to the freezing point of beef (30.5° F.) during this time. In the roof-tank car the initial cooling required less than half this time, and the coldest point remained above 37° F., indicating that had it been desired, a more concentrated cooling mixture could have been employed in this car to reduce the temperature more rapidly. The temperature difference between the warmest and coldest points in the roof-tank car was from 2° to 4° F. while in the end-tank car it was from 7° to 16° F., depending upon the outside temperature.

The results of these tests were eminently satisfactory, and the many modifications and improvements that suggested themselves during the tests gave promise of even better performance.

The Canadian National Railways built their first two overhead-cooled cars in 1937, one with heavy metal roof tanks and the other with roof baskets. The former was tested[5] along with a control car in September, 1937, with a shipment of frozen fish from Prince Rupert across the Dominion to Montreal, a trip which took approximately nine days to make. At the end of the test, just prior to unloading the fish, the difference in temperature between the warmest and coldest points in the roof-tank car was only 2.2° F. as compared with a difference of 15.4° F. in the end-tank car.

The overhead basket type car referred to above was not tested by this institution because the design was not thought to be an improvement. Tests were made by the railway company itself, however, and the results showed the design to be greatly inferior to the roof-tank type.

Several improvements that have been introduced since the test were made are: (1) the use of a false sloped ceiling several inches under the roof tanks to catch drips that may fall from the tanks when shipments of unfrozen products are unloaded; (2) a false wall inside the car to intercept radiation from the main walls and to provide space for positive air circulation; (3) raised outlets to the brine tanks to retain an amount of brine sufficient to assure a uniform temperature over the entire bottom of each tank; (4) a system of drainage whereby the overflowing brine floods the false wall and the floor of the car and thus gives up some of the refrigeration that is ordinarily lost in the waste brine. These refinements have all proved their value and will be incorporated in the future Canadian roof-tank refrigerator cars.

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[3] O. C. Young, Prog. Rept. (Pacific) of the Biological Board of Canada, No. 19, p. 17, 1934.

[4] O. C. Young, Prog. Rept. (Pacific) of the Biological Board of Canada, No. 29, p. 3, 1936.

[5] O. C. Young, Prog. Rept. (Pacific) of the Biological Board of Canada, No. 34, p. 18, 1937.

Both the larger Canadian railway companies have intimated that any refrigerator cars built in the future will be of the roof-tank type. The Canadian Pacific have ten cars[6] of this type operating at present and the Canadian National, besides three experimental cars, will build fifty in the near future.[7] The Canadian National cars will have other improvements besides overhead refrigeration. This company, in collaboration with the Canadian National Research Council, has developed a new type of underslung heater for winter use, and these will be installed in the new refrigerator cars to make a much improved unit.

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[6] O. C. Walker, Ice and Refrigeration, 94:2, 1938.

[7] Anonymous, Ice and Refrigeration, 96:332, 1939.

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MOLLUSCAN SPECIES COMMON TO WESTERN NORTH AMERICA AND JAPAN

By A. Myra Keen

As one looks at a North Polar projection map or at a globe, one sees an almost continuous chain of islands linking the North American continent with the Asiatic. From the island-dotted Alaskan Gulf stretch the Aleutian Peninsula and Aleutian Islands across Bering Sea almost to Kamchatka; southward from Kamchatka the Kurile Islands continue the chain to Japan. It is a poor imagination indeed that cannot see migrating across this convenient bridge wave after wave of marine life.

Consonant with the opportunity for migration is the arresting similarity of the Japanese molluscan fauna—particularly that of the northern part of Japan—with the fauna of the Aleutian and Californian provinces. Certainly more than half and perhaps as much as two-thirds of the generic units recognized on either coast are present upon the other; small wonder, then, that conchologists and paleontologists have had much to say in the literature about the interrelationships of the two areas.

J. P. Smith (1904), though recognizing the presence of a deep channel between the Aleutian Islands and the coast of Kamchatka, maintained, nevertheless, that the marine faunas of Japan and the western coast of America have a large number of species that are the same; further, that "the identical species are not merely circumboreal, for many of them have never been found in the Boreal region." In support of this contention, he cites 48 presumably identical species; of these, at least 28 are certainly misidentifications, leaving a scant 20 identities between faunas either of which numbers nearly two thousand kinds. (For the West American fauna Dall lists 1948 species; for the Japanese, Pilsbry lists 1891.)

Next to discuss these faunas, Dall (1921) also mentions the chasm of deep water extending from the area between the end of the Aleutian chain and the Russian possessions. "The separation of the areas," he says, "has apparently existed long enough for the modification of the American and Okhotsk faunas to specific differences in many originally identical forms." He cites, however, some 50 species as still ranging between the two areas.

More recently, the Japanese paleontologists Nomura and Hatai (1936), accepting the earlier records at face value, have published a partial list of 47 Tertiary and Recent species assumed to be identical; of these, 19 are unquestionably misidentifications, and several others are open to doubt. On the basis of their list, Nomura and Hatai postulate a number of migrations during Tertiary time between the Asiatic and American continents.

Because of the repeated attempts at application of molluscan evidence to problems of paleogeography, it seems wise to review, in the light of present-day conceptions of species units and of ranges, the bases upon which the generalizations of Smith and later workers have been founded. The present study is part of a program of biogeographic studies being carried on by members of the Geology Department of Stanford University.

From published catalogues of Japanese mollusks there was compiled a list of species the type localities of which are east of the Aleutian Islands; conversely, a list was made of species included in catalogues of West American mollusks the type localities of which are west of Bering Sea. The catalogues of Dall, Dunker, Lischke, Pilsbry, and Hirase, and faunal lists by several Japanese authors, were consulted. The combined lists totaled 66 species of living Gastropoda and Pelecypoda said by one author or another to be common to the Japonic and American areas. Next, an attempt was made to obtain authentic specimens of all these species for comparison. During three years of exchanging with several Japanese collectors, specimens of approximately half of the cited species were obtained. At first glance this may seem an unduly low proportion of success. One must remember, however, that a considerable number of the published records are used upon sporadic or unique occurrences and that several more of the forms reported are so rarely taken in Japan that many Japanese collectors have not themselves seen specimens.

Table 1 is a list of the species studied, with comments on the allocation of a number of forms and indication of the material seen. The listed species are

TABLE 1

Molluscan Species Common to Japan and Western North America

Species of Pelecypoda	Range continuous		Range discrete	Material seen		Comments (especially, relative to Japanese species)
	Alaska–Japan	Calif.–Japan		Japan	West. Am.	
Astarte borealis (Schumacher)	x				+	Circumboreal
Botula californiensis (Philippi)			x	+	+	*Unnamed
Clinocardium californiense (Deshayes)	x			+	+	Valid identity
C. ciliatum (Fabricius)	x				+	Circumboreal
C. nuttallii (Conrad) ["corbis"]		x		Fig.	+	Probably valid
Gari californicus (Conrad)		x		+	+	Probably valid
Lasaea rubra (Montagu)			x	*	+	**L. nipponica* Keen
Lithophaga aristata (Solander)			x		+	
Lucina acutilineata Conrad			x	*	+	*Unnamed form
Macoma brota Dall	x			+	+	Not identical ?
M. calcarea (Gmelin)	x				+	Circumboreal
M. inconspicua (Brod. & Sby.)		x			+	
M. incongrua (Von Martens)	x				+	Valid
M. irus (Hanley) ["inquinata"]		x			+	
M. nasuta (Conrad)			x	Fig.*	+	*=*M. tokyoensis* Makiyama
M. secta (Conrad)			x	*	+	*Unnamed form
Modiolaria nigra Gray	?				+	Circumboreal
Mya arenaria L. (see M. japonica)					+	
M. japonica Jay	?			+		
M. truncata Linné	x			Fig.	+	Circumboreal
Mytilus edulis Linné		x			+	Circumboreal ?
Pholadidea penita (Conrad)		x		Fig.*	+	*Misidentified
Pododesmus macroschismus (Deshayes)		x		+	+	Probably valid
Propeamusium alaskense (Dall)	x				+	
Protothaca staminea (Conrad)		x		*	+	**P. euglypta* (Sby.)
Sanguinolaria nuttallii Conrad			x	*	+	**S. olivacea* Jay
Saxicava arctica (Linné)		x		*	+	**S. awana* Yokoyama
Schizothaerus nuttallii (Conrad)			x	*	+	*Unnamed form
Septifer bifurcatus (Conrad)			x	*	+	**S. keenae* Nomura
Serripes groenlandicus (Gmelin)	x			Fig.	+	Circumboreal
S. laperousii (Deshayes)	x			+	+	Probably valid
Siliqua patula alta (Broderip and Sowerby)	x			+	+	Probably valid
Solen sicarius Gould			x		+	Misidentified?
Spisula polynyma voyi (Gabb)	x			+	+	Probably valid
Tellina salmonea Carpenter		x			+	
T. lutea Wood	x			Fig.	+	Probably valid
Volsella modiolus (Linné)		?		*	+	*Japanese form unnamed

TABLE 1—(*Continued*)

Molluscan Species Common to Japan and Western North America

Species of Gastropoda	Range continuous		Range discrete	Material seen		Comments (especially, relative to Japanese species)
	Alaska–Japan	Calif.–Japan		Japan	West. Am.	
Acmaea pelta Eschscholtz		x		+	+	Probably valid
Acmaea scutum Eschscholtz		x			+	
Aforia circinata (Dall)	x			Fig.	x	Valid
Beringius indentatus Dall	x					
Buccinum chartium Dall	x					
Buccinum chishimanum Pilsbry	x			+		
B. mörchianum Fischer	x				+	
B. simulatum Dall	x					
Colus spitsbergensis (Reeve)	x					Circumboreal
Corolla spectabilis Dall	x					Pelagic
Crepidula aculeata (Gmelin)			x	Fig.	+	Similar in general appearance
C. grandis Middendorff	x			Fig.	+	Valid
Fusitriton oregonense (Redfield)		x		+	+	Valid
Haliotis kamtschatkana Jonas			x	+	+	Identical
Kellettia kellettii (Forbes)			x	*	+	*Unnamed species
Lacuna unifasciata Carpenter			x	*	+	*=*L. unicarinata* Smith ?
Liomesus nux Dall	x					
Littorina atkana Dall	x			+	+	Valid
L. sitkana Philippi	x			*	+	*? = *L. atkana*
Natica clausa Broderip & Sowerby (also N. russa Gould)	x			+	+	Valid
Neptunea lirata (Martyn)	x			Fig.	+	Valid
Polinices pallidus (Brod. & Sby.)	x			Fig.	+	Valid
Solariella peramabilis Carpenter			x	*	+	*Unnamed sp.
Tegula brunnea (Philippi)			x		+	(?)
Thais lima (Martyn)		x		*	+	*=*T. freycinetti* (Deshayes)
Trichotropis bicarinata Sowerby	x			+		
T. insignis Middendorff	x					
Trophon beringi Dall	x					
T. multicostatus (Eschscholtz)	x				+	
Volutharpa perryi (Jay)	x			+		Probably valid

divided into three major groups, on the basis of their distributions as cited by Dall: (1) those ranging from the Aleutian and Alaskan Gulf area to Japan; (2) those ranging continuously from California northward and westward to Japan; and (3) those occurring only in California and in Japan without intermediate records.

Table 2 is a numerical summary of table 1. Here the numbers of species for each of the distribution groups are shown in horizontal columns, first for bivalves and for univalves separately, then for the combined molluscan total. Reported identities are contrasted with the numbers of species which could be confirmed by study of specimens and by other available, though less trustworthy, evidence.

Let us consider the results shown in the lower row of this table: About half (34) of the species occur, in America, only in the Aleutian–Alaskan Gulf area; one-fourth (16) would, if validly identified, range from California to Japan, and another fourth (16) would occur only at the ends of this arc with out intermediate representation. Scrutiny of specimens, however, does not confirm this picture, especially for the species said to occur in California. It is true that most of the circumboreal and Alaskan species probably do range westward to northern Japan, though even here there are several species in which Japanese specimens are consistently different and separable from Alaskan and Arctic forms. Parenthetically it may be noted that of the total 66 species, 11 appear to be circumboreal, a larger proportion than was implied by Smith. Of the 16 species supposed to range continuously from California to Japan, not more than 7, and probably fewer than 5, can be accepted as valid. Of the 16 discontinuous species, not more than 4, probably not more than 2, can be accepted. Although most success in obtaining comparative material was for these latter two categories—the California-to-Japan groups—it happens that no Japanese specimens or adequate illustrations have been available for 3 of the 4 species the ranges of which are possibly discontinuous, so that a statement of exact number is as yet impossible. Even so, the relative proportions which these groups constitute in their respective areas can be construed fairly well by the use of percentages. In the faunal area represented by the Bering Sea, about 5 per cent of the species present there range southward as far as to Puget Sound on the east and to northern Japan on the west. Of the faunas in California and in Japan, only about 0.3 per cent range the entire intermediate distance; not more than 0.2 per cent can be said to occur in the two areas without also occurring in Alaska.

TABLE 2

NUMERICAL ANALYSIS OF MOLLUSCAN SPECIES COMMON TO JAPAN AND WESTERN NORTH AMERICA

	Distribution continuous		Distribution discrete or discontinuous	(Circumboreal)	Total
	Alaska–Japan	Calif.–Japan			
Pelecypoda					
Reported	15	12	9	(9)	36
Confirmed	13	3 to 5	1(?)	(9)	16 to 21
Gastropoda					
Reported	19	4	7	(2)	30
Confirmed	11 to 17	2	1 to 3	(2)	12 to 22
Total					
Reported	34	16	16	(11)	66
Confirmed	24 to 32	5 to 7	2 to 4	(11)	28 to 43

Numerically, then, the large number of identical species seems an exaggeration. This is not to deny the very obvious similarities between faunas, but rather to point out that the whole problem of paleobiology is more complex than it is often assumed to be. Several morals might be drawn from the study. First, there is a psychological or human factor of bias which should be recognized. Those workers who have been most bent upon tracing migration paths have been most impressed by the large number of identical species; not stopping to consider the number of unidentical forms that make up the bulk of the faunas, they have drawn a distorted picture. Second, it becomes evident that illustrations alone are not to be trusted in making these significant identifications; only specimens—and those preferably from several localities—

should be used in reaching a decision; and furthermore, the resultant findings should be checked by several specialists. Lastly, the paleobiologist needs more than a passing knowledge of the Recent faunas of all areas concerned before attempting to trace migration paths of the past, for the latter type of study, with its problems of stratigraphy and the frequently poor preservation of fossils is complex enough without the added obscurity of misidentified species.

Fundamentally, the foregoing criticisms refer to a disregard of the necessary use of controls in deriving sound conclusions. The same criticism may apply also to the customary procedure in tracing paths of migration. The course ordinarily taken, when any similarity between faunas is noted, is to seek additional faunal evidence, present and past, in support; and as a final step to postulate shore lines for past epochs which would account for the present distribution. This involves circular reasoning, in that these past epochs—Eocene, Oligocene, Miocene, and so on—are themselves defined on the basis of contained faunas. By the course just described, no independent criterion can be utilized as a control. Rather, it would seem that the correct procedure should be on this order: first, to work out stratigraphic columns independently of marine faunas; from these to postulate continental shore lines; lastly, by inspection of sequences of such shore lines, arranged in chronologic order, to discover opportunities for migrations of marine faunas. Otherwise, using biologic evidence alone, the zoögeographer and the paleontologist would seem to have no sound basis for conclusions on the origins or the intermigrations of faunas.

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AN INTRODUCTION OF AN ATLANTIC CRAB INTO SAN FRANCISCO BAY

By Lowell L. Jones

Rhithropanopeus harrisii is a small crab of the family Xanthidae. It is native to the temperate Atlantic Coast of North America, living especially in the brackish and fresh waters of bays and estuaries. During the past two years this species has been found in a few localities in San Francisco Bay. Specimens were sent to Dr. Waldo Schmitt of the U. S. National Museum, who identified them. Dr. Schmitt suggested that the crabs may have been introduced in shipments of oyster spat, since they are abundant in oyster beds of the Atlantic Coast. Certain mollusks are known to have been introduced here in this way.

The localities in San Francisco Bay where the crabs have been found are mostly in the region of Carquinez Strait, near the towns of Benicia, Martinez, Vallejo, and Crockett. This region is in the northern part of the bay, near the mouths of the Sacramento and San Joaquin rivers. During and immediately after the rainy season, the water of this part of the bay becomes nearly or entirely fresh, owing to the inflow of large amounts of river water. The *Rhithropanopeus* of this region are found under rocks on a muddy substrate. The only other location in the bay where they have been found is Lake Merritt, in Oakland. Lake Merritt is a body of brackish water connected with the bay. As in the Carquinez region, the water here becomes fresh or nearly so at times. In Lake Merritt the usual habitats of these crabs are the interstices of masses of a calcareous tube worm, *Mercierella enigmatica.*

The most abundant crab of San Francisco Bay is *Hemigrapsus oregonensis.* This species can live in extremely dilute brackish water, down to a salinity of only 0.4 parts per thousand, but can not live in completely fresh water. The spring of 1938 was one of heavy rainfall, with a consequent extreme lowering of the salinity of the bay. Carquinez Strait had completely fresh water in the late spring and early summer of that year. During that time no *Hemigrapsus oregonensis* were found there, but *Rhithropanopeus harrisii* was abundant. In the autumn of 1938, after the water in Carquinez Strait had been brackish for some time, a few *Hemigrapsus oregonensis* could be found. The winter and spring of 1938–39 had a rainfall below normal in California and the salinity of the bay did not become very low in any part. Having had more than a year free from the deleterious effects of fresh water, the *Hemigrapsus oregonensis* have now migrated into Carquinez Strait in such numbers that they appear to be more numerous than the *Rhithropanopeus.* Since the two occupy practically the same ecologic niche, this increase has doubtless caused a decrease in the number of the latter species. *Hemigrapsus oregonensis* is far more active and aggressive than *Rhithropanopeus,* so that competition for food and shelter between the two could only result in the dominance of *Hemigrapsus.*

It seems apparent from these observations that *Rhithropanopeus harrisii* can become established in San Francisco Bay only in those regions where the water occasionally becomes fresh, thereby killing the native *Hemigrapsus oregonensis.* The situation in the tube worm association of Lake Merritt may be somewhat different, since *Hemigrapsus* is probably too large to accommodate itself to this habitat.

In conclusion I should like to point out that almost all the species of marine invertebrates which are known to have been introduced on this coast have become established only in bays. Besides *Rhithropanopeus,* these are the clam *Mya arenaria,* the shipworm *Teredo navalis,* the snails *Urosalpinx cinereus* and *Ilyanassa obsoleta,* the tube worm *Mercierella enigmatica,* and several species of hydroids. While this restriction to a bay habitat may be largely due to the means of introduction, as of those brought in with oysters, there is probably another factor which should be mentioned. The Pacific Coast of this country is essentially an open rocky or sandy coast, and is deficient in bay areas as compared with the Atlantic Coast. An abundant and diversified fauna, adapted to the peculiar conditions of the bay and estuarine habitat, has not therefore developed on this coast. Because of this lack, many ecologic niches exist which are not filled by native species, but which can be filled by species from a region where a great extent of bay area has led to the development of a fauna thoroughly adapted to that environment.

CHITONS IN THE PACIFIC OCEAN

By Isao Taki

The exploring expeditions to the North Pacific by the English, the Russians (Middendorff, Schrenck), and the Americans (Western Union Telegraph Expedition) resulted in the discovery of several species of chitons. Later, a multitude of new forms were added by expeditions such as the "Magenta," the "Challenger," the "Albatross," and the "Siboga." On investigating the distribution of chitons in the Pacific, it has become clear that some of them are found in the restricted localities characteristic of genera and species, and such may well be considered as indicators.

The Pacific Ocean, as compared with other great bodies of water, is very rich in species of chitons. They number about 630, in 7 families and 92 genera. As a matter of fact, the Pacific Ocean possesses all known genera, except for only a few endemic ones peculiar to other oceans.

As in other animals, the faunistic elements of chitons in any locality consist of endemic and cosmopolitan forms. The Pacific Ocean may be divided roughly into four regions with regard to the occurrence of the endemic genera of chitons, namely: (1) the North Pacific; (2) the South Pacific, including the Antarctic Sea; (3) the southwestern Pacific, mainly the north and east coastal regions of Australia; and (4) the east coast of the Pacific, in the main the coastal region of Central and South America. It may here be mentioned that no endemic genera occur in the shores of the oceanic islands.

The following genera are peculiar to the North Pacific region: *Oldroydia, Spongioradsia, Schizoplax, Nuttallina, Mopalia, Placiphorella, Katharina, Cryptochiton, Lepidozona, Callistochiton*. Of these *Oldroydia, Spongioradsia, Schizoplax, Nuttallina, Katharina,* and *Cryptochiton* each have a very few species and are limited in their distribution to the extreme north of the Pacific, while *Mopalia, Placiphorella, Lepidozona,* and *Callistochiton* flourish better on both coasts of the Northern Pacific, ranging from Bering Strait down to the Temperate Zone. The North American coast yields the majority of the species of *Mopalia, Placiphorella, Lepidozona,* and *Callistochiton* and such characteristic genera as *Basiliochiton, Ploiochiton, Dentrochiton, Pallochiton, Rhombochiton,* and *Diochiton,* whereas the Japanese shore has a few representatives of the four genera mentioned above, besides a peculiar group, *Ikedaella.*

From the South Pacific region very few forms have been found, because chitons generally flourish better in the littoral zone, and because this region has not been well explored. A few species of the primitive genera *Himiarthrum* and *Notochiton* are the only known representatives of the Antarctic sea.

The southwestern Pacific region is by far the richest in genera and species of chitons of any in the world. On the eastern and northern coasts of Australia, chitons are estimated at about 44 genera, among which 29 are the endemic ones. Iredale and Hull reported about 160 species of chitons from the Australian region, and about 70 species from the Neozelanic region. The important genera characteristic of this region are *Terenochiton, Eudoxochiton, Fremblya, Lophochiton, Cryptoconchus, Choriplax, Heterozona, Stenochiton, Callistelasma, Sypharochiton, Onithochiton, Schizochiton, Lorica,* and *Loricella.* Besides these, *Ischnochiton* s. l., *Acanthochiton, Notoplax* s. l., and *Rhyssoplax* contain a number of species in this region. *Plaxiphora* s. l., *Icoplax, Lucilina,* and *Cryptoplax* are also abundant in species. *Ischnochiton* and *Notoplax* are so much differentiated in this region that they can be divided into several sectional groups, a condition unknown in any other part of the world.

The South American Region is not very rich in genera and species, though such genera as *Mopaliella, Callistoplax, Enoplochiton, Radsia, Chondroplax, Amaurochiton, Mesotomura,* and *Tonicia* are well represented. Of these genera, *Mopaliella, Radsia,* and *Mesotomura* are peculiar to this region. There occur some endemic species belonging to the genera common to the Austro-Neozelanic region.

Lepidopleurus, Acanthochiton, Ischnochiton, and *Chiton,* all in broad sense, are cosmopolitan, but they are by far at their richest in the Pacific, being differentiated into several minor groups and numerous species. *Ischnochiton* and *Acanthochiton* thrive better, especially along the shores of the Australian and the North American regions, and rather poorly along the South American and Japanese shores. *Lepidopleurus* has been collected not only from the shores around the Pacific, but also from the deep sea far from the continents. *Chiton* s. l., with endemic subgenera, thrives on every shore of the Pacific, along the coasts of the continents as well as around the oceanic islands.

Adult chitons by their own locomotion, and their larvae by means of oceanic currents, may be able to reach the wide area of the ocean, yet as a matter of fact the distribution of chitons is well fixed. The most important factor determining their distribution seems to be the temperature of the water. Especially a great difference of temperature such as the contact planes of the warm and cold currents may be the most effective barrier to their distribution. The cold currents of the Pacific are always checked off by the warm currents, submerging under the warm currents. These contact planes are very differently situated in different places. For example, on the Pacific coast of Japan the plane is rather oblique from the surface at Inubô-zaki to about 500 m. at Tosa Bay while on the coast of the Japan Sea the inclined plane ranges from the surface at the southern end of Hokkaidô to a depth of about 100 m. at the western end of Honsyû (the main island). The inclination of the barrier, therefore, on the Pacific coast is very steep, while on the Japan Sea it is so slight that the barrier is almost horizontal at the depth of about 100 m.

On the North American coast the cold current is checked off the shore of California, and on the South American coast off the coast of Chile, and on the Australian east coast off Sandy Cape. The boundaries of marine fauna have hitherto been roughly represented by the lines drawn on the map where warm and cold currents meet below. More strictly, they should be considered as the inclined plane where these currents come in contact with each other. Accordingly, a species which occurs relatively in shallow water in higher latitudes may be found in the deep water in lower latitudes. *Leptochiton mesogonum,* for example, was dredged from a depth of 688 fathoms in the Bering Sea and at 1588 fathoms off the coast of British Columbia; *L. luridus,* at 48 fathoms in Puget Sound and at 1270 fathoms at Panama; *Tonicella saccharina* occurs at Unalaska at 3 to 13 fathoms, and at San Diego, California, at 101 fathoms; *Tonicella lineata* is abundant on the shore of Akkesi, Hokkaidô, and is dredged from a depth of about 30 m. at Mutu Bay. It may be recalled that according to Dall (1878) *Tonicella marmorea* inhabits depths of from 5 to 100 fathoms according to temperature.

It may also be pointed out that the range of distribution of each species is controlled by the corresponding isothermal line.

As mentioned before, *Ischnochiton* and *Acanthochiton* are shallow-water forms. *Schizoplax* is littoral; *Cyanoplax, Nuttallina, Katharina* and *Cryptochiton* occur invariably between tide marks in the North Pacific. *Schizochiton, Onithochiton, Sypharochiton, Stenochiton, Heterozona, Choriplax,* etc., are known only from the beaches of the Australian region. The highly specialized genera *Liolophura, Acanthopleura, Rhyssoplax,* and *Squamopleura* live near the tide marks of Japanese and Australian shores. Of the genera characteristic of South America, *Tonicia, Mesotomura, Enoplochiton, Amaurochiton,* etc., are shore forms.

Mopalia, Placiphorella, Lepidozona, Callistochiton, genera of Callochitonidae and Lepidochitonidae, *Notoplax,* and *Cryptoplax* are by far the most abundant of all shallow-water species. Some *Ischnochiton, Lepidozona, Placiphorella,* and *Basiliochiton* are dredged from the depths of less than 50 fathoms. *Plaxiphora* (100–300 fm.), *Trachydermon* (100–300 fm.), *Chaetopleura* (200 fm.), and *Lepidopleurus* (300–400 fm.) have been collected from the moderate depths.

The real deep-sea forms are very few and restricted entirely to *Lepidopleurus* s. l., the most primitive genus of all chitons; for example, *L. belknapi* was dredged from 1006 fm. (28° C.) in the North Pacific, and from 1050 fm. (2.78° C.) near the Philippine Islands; *L. benthus* from the north of Hawaii in 2300 fm. (1.67° C.), the greatest depth thus far recorded in the Pacific.

The littoral species spend their younger life in moderate depths and approach nearer the shore as they grow larger, while the adults of some species live at moderate depths and their young occur in shallow water. Thirty-eight specimens of *Lepidozona albrechti* dredged from Onagawa Bay in depths of from 8 to 30 m. measured from 4 to 10 mm. in width of the fourth valve, while the larger species of more than 15 mm. were collected on shore. It was reported by Dall that deep-water specimens of *Hanleya mendicarina* were much larger than those from shallow water. This seems to indicate that the chitons have a tendency to shift their habitats with respect to depths as they grow older.

The primitive species are limited to the family Lepidopleuridae, *Lepidopleurus* in the North Pacific and *Terenochiton* in the southwestern Pacific, both occurring at a depth of from 50 to 2300 fathoms. A few species of the former have been dredged from great depths in the tropical Pacific. *Hanleya* and *Hemiarthrum* of this family are known only from the north and south extremities of the Pacific, respectively. The highly specialized families Chitonidae and Acanthopleuridae are by far the richest on the shore of temperate and tropical regions along all the continents surrounding the Pacific. The intermediate groups between the two groups above mentioned, such as Lepidochitonidae (including *Lepidochiton, Tonicella,* etc.) and Callochitonidae (including *Callochiton, Icoplax, Eudoxochiton,* etc.), have their habitats in the moderate depths, and thrive exclusively in the cold waters near the poles.

Chitons in the Pacific show bipolarity not only in their horizontal distribution as in *Liolophura, Ischnoradsia,* etc., but also in their systematic relations; for example, *Leptochiton* of the North Pacific cannot be separable from *Teranochiton* of Australia from their external features. Counterparts of *Callochiton, Mopalia, Cryptochiton, Callistochiton,* and *Onithoplax* are *Levicoplax, Frembrya, Choriplax, Callistelasma,* and *Onithochiton,* respectively. It may be concluded from these facts that the northern and southern hemispheres yield closely related forms.

Lucilina thrives on Austro-Asiatic coasts, and the corresponding group *Tonicia* is found only from the South American shore. *Rhyssoplax* is the dominant group of Chitonidae in the eastern hemisphere and the corresponding group *Chiton* s. s. in the western hemisphere.

Cryptochiton of the North Pacific is by far the largest of all chitons, attaining a size of more than 300 mm. in length; *Amaurochiton* is one of the largest genera of Chile; *Plaxiphora* may be mentioned as the largest in the Australian region, measuring 120 mm. in length; *Acanthozostera* in the tropical area of the Indo-Pacific region measured 100 mm. in length.

Lepidopleurus hirasei from Japan is one of the smallest species in the North Pacific, ranging in size from 3 to 4.5 mm. *Lophochiton finlaryi* of the Neozelanic region is a little longer than 2 mm. *Terenochiton niger* and other congeners from the Australian region measure 4 mm. in length.

There is no relation between the body size and the systematic position. The primitive forms are usually small, rarely attaining medium size; they do not live on the exposed rocks of the shore. The largest groups, however, are invariably littoral, even occasionally being exposed to the air. Hence the body size is closely related to the habitat of chitons. It may not be amiss to consider that the bottom of moderate depths is the ancestral habitat of chitons, for the reason that both primitive and juvenile forms occur side by side there.

Certain genera peculiar to the North Pacific show a wide range of distribution, extending to the North Atlantic through the Arctic Sea. The characteristic genera, such as *Hanleya, Tonicella, Amicula, Chaetopleura,* and *Lepidopleuroides,* live together in these waters.

The species common to the Pacific and Atlantic coasts of North America are exceedingly small in number. *Ceratozona* is found on both sides of Central America; *Cyanoplax* is known from the west coast of North America and the West Indies; *Callistochiton shuttleworthianus* is reported from both the Galápagos Islands and Key West, Florida.

The southern region of South America shows the faunistic similarity of the Pacific to the Atlantic coast, being much influenced by the warm Brazilian current, which extends farther south to the Strait of Magellan and to the west coast.

A very few genera have been known in the circumpolar Antarctic sea. One species of *Hemiarthrum* was recorded from the south of New Zealand, and several species of *Icoplax* from the adjacent territories of Australia.

The western Pacific is so intimately connected with the Indian Ocean in faunistic relation that there occur genera endemic and common to these oceans, such as *Thaumasthochiton, Cryptoplax, Squamopleura, Acanthozostera, Acanthopleura, Lucilina, Onithoplax. Trachyradsia* and *Aerilamma* are peculiar to the Indo-Australian region. *Onithoplax, Lucilina,* and *Thaumasthochiton* have a wide range of distribution, from the Indian Ocean to Japan through the Philippine Islands. *Cryptoplax* is very prevalent on coral reefs of the tropical and subtropical regions of the Indo-Pacific. *Squamopleura* is confined in its distribution to the region from northern Australia to Formosa inclusive of the Malay Archipelago. The chiton fauna of southern Japan consists of the Indo-Pacific as well as Australian elements.

SUMMARY

1. About 630 species of chitons occur in the Pacific Ocean.

2. Around the oceanic islands chitons are very poor in species, while they abound in the marginal area of the continents.

3. The endemic genera occur near the continents and are never found around the oceanic islands.

4. Of the horizontal distribution of chitons the following may be said:

a) Their ranges usually run along the isothermal line characteristic of each species.

b) The great difference in temperature between the cold and warm currents forms a barrier in the horizontal distribution.

c) The North Pacific species extend from the Bering Sea farther southward on the American coast than on the Japanese coast.

d) The South American coast of the Pacific is similar to the eastern coast in regard to the chiton fauna.

e) Some Australian and Indian genera are carried by the warm current farther north to as far as Japan.

f) A few genera are distributed discontinuously in the northern and southern ends of the Pacific (horizontal bipolarity).

5. Regarding the vertical distribution:

a) Chitons are distributed from the shore to a depth of about 2300 fathoms.

b) In the temperate zone the shore forms are by far the most abundant in the species as well as in individuals.

c) In the tropical and the polar regions chitons flourish better in shallow waters and a few are found on exposed rocks when the tide recedes.

6. As to taxonomic considerations:

a) The primitive genera occur in the deeper part of the sea, while the highly specialized genera are usually near the shore and the intermediate genera live in shallow water.

b) In the northern and southern hemispheres certain groups have their counterparts related systematically (systematic bipolarity).

c) There is no relation between the body size and the systematic position, but the primitive species are mostly small.

7. Chitons of large size are all littoral, while those of small size are found either in shallow or in deep water.

8. Regarding the chiton fauna in relation to that of other oceans:

a) The Pacific Ocean has, besides its own endemic forms, species occurring in neighboring oceans.

b) The Indian Ocean, particularly its western region, has forms resembling most closely those in the Pacific.

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CAN EKMAN'S EASTERN PACIFIC BARRIER ("OSTPACIFISCHE SPERRE") BE MAINTAINED AND IS EKMAN'S DIVISION OF THE PACIFIC FAUNA INTO A WESTERN PACIFIC AND AN EASTERN PACIFIC JUSTIFIED?

By G. STIASNY

EKMAN in his masterful book (1935, *Tiergeographie des Meeres*) has established the "ostpacifische Sperre," an Eastern Pacific Barrier. So he calls the broad empty space devoid of islands between eastern Polynesia (Marquesas Islands) and the Central American coast, and thus divides the Pacific into an Indo-western Pacific and an eastern Pacific region. He accordingly speaks about an Indo-western Pacific fauna with Indo-Malayan character which is closely related to the West Indian fauna, while the fauna of the eastern Pacific is very different. In consequence he regards the "ostpacifische Sperre" as the most important interruption in the circumtropical distribution of the warm-water fauna.

Ekman apparently believes the whole region between the Marquesas and Central America to be a very old part of the earth's crust and of a very homogeneous character with respect to its relief. There are, however, many important geologists who believe this part of the globe must have foundered in Tertiary or post-Tertiary times and that there were a large northern and a large southern continent separated perhaps by a narrow equatorial belt.

The configuration of the bottom of this part of the Pacific is not so uniform by far as Ekman seems to believe. There is, in the first place, the diagonal Easter Island threshold, and the recent discoveries of the *Carnegie* and other expeditions have shown that there are many deeps, troughs, and submarine ridges which on the whole give the impression of a much more complicated relief of the bottom than hitherto has been thought to exist.

The fauna of the eastern Pacific is said by Ekman to be very different from that of the Indo-western Pacific. He, however, feels obliged to restrict the differences to the littoral fauna alone and must confess that they are much less remarkable in the pelagic and abyssal faunas. I cannot admit that a barrier restricted only to the littoral fauna and nearly invalid with respect to pelagic and abyssal forms may be called "most important." Ekman tries to justify his view by many examples. I can discuss here only one. The genus *Anguilla* is distributed in the eastern and western Atlantic, and in the central and western Pacific, but is not represented in the eastern Pacific. Ekman attributes the absence of the genus *Anguilla* in the eastern part of the Pacific in the first place to historical reasons. We know, however, from recent observations by Schmidt, Bruun, and others that the reason for the absence of *Anguilla* in certain parts of the ocean is to be sought for principally in lack of favorable conditions for spawning.

Ekman, I believe, overestimates considerably the importance of his so-called Eastern Pacific Barrier.

There are, I believe, sufficient reasons to assume that the Pacific on the whole does not form a homogenous zoögeographical region. I should like to divide the Pacific into two large zoögeographical provinces, which, however, do not correspond with the two regions of Ekman, but with two regions of strongly different geological character. The barrier between the two does not agree with Ekman's Marquesas line. It is Born's (1932) so called "Andesitlinie" ("Andesitic line") and the identical "imaginary line" of Ladd (1934). This line runs along the east coast of the Marianas and Palau Islands to Yap, then, bending eastward, runs from Truk, New Ireland, and the Solomon

Islands to Fiji, and then, bending sharply (leaving Samoa eastwards), runs along the Tonga, Kermadec, Catham, and Bounty Islands, on the east side of all these.

This barrier having been established hitherto only for the distribution of nonmarine Mollusca, Coleoptera, and other land animals (for example, crocodiles), is, I believe, valid also for various groups of marine animals too, for instance, for all the different worms forming the "Palolo" (*Eunice, Lysidice, Nereis*), many Alcyonaria, Gorgonarians, Actiniae, Holothurians, Hydrophiidae, some crustaceans, etc.

I believe the "Andesitlinie" to be the true barrier between the two faunas of the Pacific and not the Marquesas line of Ekman. I must admit, however, that the marine fauna of the Hawaiian Archipelago offers many difficulties. It may form a separate province of animal distribution which cannot be united either with the western or with the eastern Pacific fauna.

HYDROID DISTRIBUTION IN THE PACIFIC

By C. McLean Fraser

In attempting to make a study of the comparative distribution of the hydroids in so large an area as the Pacific Ocean, so many difficulties are met with that only the most general conclusions concerning the nature of the distribution may be reached. It is probable that the same thing may be said in regard to most, if not all, of the other faunal groups.

In the first place, no two large sections of the ocean have been equally exploited. In some sections, for example, portions of the coast of Australia, of Japan, of British Columbia, and of California, enough collecting has been done to provide a fair picture of the extent of the hydroid fauna (there is no hope that a complete picture can ever be obtained). Other sections have been explored in descending order of efficiency, until such sections as Polynesia, and the west coast of the United States from the Golden Gate to Cape Flattery, are reached, almost devoid of distribution records.

Positive distribution records must form the basis for any conclusion. It is quite unsafe, as well as wholly unwise, to make the statement that a species does not occur in any area because its occurrence there has never been reported.

As no one individual can possibly be familiar with the conditions in all parts of the Pacific, it is impossible to evaluate fairly the distribution records that have been made, or to come to any worthwhile conclusion as to how complete they may be.

In the second place, many if not most of the collections are selective rather than representative. Usually each hydroid collection is simply a portion of a general collection made on a dredging expedition or on a shore trip, or both. It is made, or supervised, by a single collector, who necessarily has a large amount of material to take care of and hence can give but a limited attention to any one group. It is evident, then, that in general only the more conspicuous specimens are retained. The smaller, less conspicuous, but often more important species are apt to be continually overlooked. The collection is sent off to a specialist, who can know very little about the conditions under which the collection was made, to examine and report. Such a collection cannot reasonably be compared with a collection made by a specialist who is experienced in detecting hydroids and knows where they are likely to appear, even if it is taken under otherwise similar conditions.

In the third place, the Pacific Ocean, large as it is, is not a delimited area. It is directly contiguous in some part of its bounds with each of the other oceans, and the interchange with these introduces into the problem of hydroid distribution side issues that may materially influence the consideration of some of the aspects of the situation. Thus an examination of distribution in the Pacific should entail some knowledge of world-wide distribution.

In the fourth place, there are difficulties inherent in taxonomy itself. Nowadays there is much discussion on the validity of species established on morphological characters. Some physiologists, experimental zoölogists, and geneticists declare that no species should be established until its physiological and cytological characters, past, present, and future, have been definitely determined. This is very fine in theory but utterly hopeless in practice. This is not the place to discuss the question. It may suffice to say that with any change in function there is almost always a definite change in structure. The morphological changes or differences are readily observable; the functional changes are determined only by experiment, which is of no value for future reference unless it is associated with morphological characters.

It is quite true that as long as human nature is as it is, there will be differences of opinion concerning the amount of difference in morphological characters necessary for specific differentiation; yet even here there is agreement for the great majority of hydroids. It is not here that the main difficulties arise.

The main shortcomings in taxonomy have their basis in a lack of literature for reference. This is a real stumbling block to an embryonic taxonomist. There are very few libraries in the world that are well equipped with taxonomic literature. Much is needed to make any satisfactory start in the work. It follows that a taxonomist is forced to build up a reference library of his own. Reference papers published in the last twenty or thirty years can ordinarily be obtained without much difficulty, but the earlier papers, often of more importance than the more recent ones, are almost sure to be long out of print and almost unobtainable. Progress must necessarily be slow. The taxonomist, therefore, becomes well equipped only when he no longer has to depend so much on his equipment. When he needs it most, on entering the field, it is very little in evidence. As more and more references are accumulated, it becomes necessary to revise early decisions, so that a reviewer who is not familiar with the whole situation is much at sea in evaluating his records.

As one follows through the papers published by one individual over a period of years, this change of opinion may be very evident. I have in mind a hydroid taxonomist in the Pacific region who published at intervals over a period of forty-five years. By reviewing his publications one can readily surmise how fast his library grew during all those years.

With all these difficulties in mind, why should one have the temerity to attempt to draw conclusions? The very difficulties serve as a challenge, and any serious attempt at solution should be worth while.

To begin an examination of hydroid distribution in the Pacific, it was necessary to assemble the distribution records in all the publications, more than two hundred of them, dealing with the Pacific region. In order to make these records readily available for the purpose in hand, the whole Pacific region was divided, somewhat arbitrarily, and yet with due geographic consideration, into fifteen areas, as follows:

1. The coast of Canada and the United States
2. Mexico and Central America to Balboa
3. South America from Balboa to the southern boundary of Peru
4. The rest of the South American coast
5. The Galápagos Islands
6. The Hawaiian Islands
7. Siberia and Korea
8. China and southern Asia to Singapore
9. Japan
10. The Philippines
11. The East Indies and Micronesia
12. Australia
13. New Zealand
14. Polynesia
15. Antarctic regions adjacent to the Pacific

Of these divisions, Polynesia has little significance, as there have been few hydroid records from that region. This may not be entirely for lack of exploration. In the course of the Fiji–New Zealand Expedition of the State University of Iowa in 1922, C. C. Nutting and his associates spent nearly a month in Fiji. For two weeks they collected around the shores of the small island of Makuluva, nine or ten miles from Suva, and although Nutting was the leading authority on hydroids in North America, he failed to observe a single colony during his stay there.

Some interesting records have been obtained from some of the expeditions to the Antarctic regions, but they are not numerous. Even this perhaps should not be considered here, as the southern limit of the Pacific Ocean is usually considered to be 40° south latitude.

In assembling the records, a filing card was used for each species, on which was placed each regional distributional record, with the author and the date of the paper supplying the information. Obvious synonymies were eliminated, but no attempt was made to clear up the synonymy completely. That would have been too long a job. As the synonym usually affected the list in one region only, it made little difference to the general comparison. From these cards a complete distribution table was prepared to show graphically the nature of the distribution of each species.

TABLE 1

Number of Species Common to Each Two Regions

No. of species	Region														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	..	60	27	29	38	10	28	30	38	7	14	22	11	1	8
2	..	..	54	19	48	8	4	17	25	7	15	20	7	1	6
3	..	..	..	15	32	3	1	8	16	4	12	13	4	0	4
4	..	..	..	..	17	5	6	13	26	3	9	28	15	1	6
5	..	..	..	..	..	7	1	13	18	6	12	10	5	1	5
6	..	..	..	..	..	..	4	5	16	5	7	12	3	2	0
7	..	..	..	..	..	..	..	6	9	1	1	6	3	0	1
8	..	..	..	..	..	..	..	..	43	10	31	35	11	4	3
9	..	..	..	..	..	..	..	..	..	16	40	57	19	3	5
10	..	..	..	..	..	..	..	..	..	..	17	23	7	2	1
11	..	..	..	..	..	..	..	..	..	..	..	73	14	5	3
12	..	..	..	..	..	..	..	..	..	..	..	..	51	7	4
13	..	..	..	..	..	..	..	..	..	..	..	..	..	3	2
14	..	..	..	..	..	..	..	..	..	..	..	..	..	..	0

When the assembling was completed, there were 1321 species in the list, but 951 of these were reported from one division only, and were of no value in showing distribution routes. The remaining 350 species that have been reported from two or more divisions formed the basis for comparison.

From the general distribution table a table was made out to show the number of species reported in common from each two of all the fifteen divisions (105 pairs); see table 1. This didn't help very much, for according to the table there were only four pairs out of the one hundred and five that did not show at least one species in common, and in some of the regions there seemed to be strong affinities with several other regions.

On scanning the list further for a way out of the impasse, it was observed that a great proportion of the duplication was due to the presence of a comparatively few species which evidently are species of such long standing that they have spread out into much of the inhabitable areas of the ocean. They are so widely distributed that it is impossible to get any clear idea of the direction or directions of their spread, or concerning whether they have all extended their sphere of influence in the same directions. Of these, *Obelia geniculata,* reported from eleven divisions, *Halecium tenellum* and *Plumularia setacea,* from ten, and *Gonothyraea gracilis,* from nine, are the most prominent.

It seemed possible that if these ubiquitous species were eliminated from consideration a clearer picture of distribution affinities might be obtained, Consequently a table was prepared with all the species (42) eliminated that have been reported from five or more regions (table 2). A glance at this table gave immediate encouragement, for this showed practically one-third of the pairs of regions with no species in common, and for each region a decided preponderance of affinities for one other region, or at the most two or three regions. It now looked as though a distribution picture could be developed.

TABLE 2

NUMBER OF SPECIES COMMON TO EACH TWO REGIONS AFTER FORTY-TWO COSMOPOLITAN SPECIES HAVE BEEN ELIMINATED FROM CONSIDERATION

No. of species	Region														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	..	37	11	9	18	4	23	13	17	2	2	6	3	0	4
2	..	..	37	5	28	4	1	2	9	0	1	4	0	0	3
3	..	..	..	3	15	0	0	0	3	0	2	1	0	0	1
4	..	..	..	..	2	1	3	2	9	0	0	12	8	0	3
5	..	..	..	..	..	4	0	0	2	0	0	0	1	0	1
6	..	..	..	..	..	..	1	2	8	3	3	5	0	0	0
7	..	..	..	..	..	..	..	4	6	1	0	3	1	0	1
8	..	..	..	..	..	..	..	..	24	5	14	16	2	0	0
9	..	..	..	..	..	..	..	..	..	11	22	33	10	0	1
10	..	..	..	..	..	..	..	..	..	..	11	17	4	0	0
11	..	..	..	..	..	..	..	..	..	..	..	55	6	1	0
12	..	..	..	..	..	..	..	..	..	..	..	..	39	3	0
13	..	..	..	..	..	..	..	..	..	..	..	..	..	0	0
14	..	..	..	..	..	..	..	..	..	..	..	..	..	..	0

Considering the regions in order, evidently there is free distribution from the coast of Canada and the United States farther south to Mexico and Central America, and, to a much more limited extent, to the northern part of South America. The distribution to the Galápagos through the Mexican and Central American areas is greater than that to South America. On the other hand, there are many species in common with Siberia, some of them extending down to the coasts of Japan and China.

In Division 2, besides the association with Division 1, there is an equally intimate association with Division 3, and almost as definite with the Galápagos.

The intimacy of Division 3 is not much divided, as it sticks with Division 2 almost exclusively. There are some species in common with the Galápagos, but there is strong indication that these made the connection through Division 2. The Division has very little in common with the coast of Chile.

The coasts of Chile and Patagonia show little association with the rest of the Pacific. They have more species in common with Australia and Japan, but there is little in Pacific literature to account for this trend.

The Galápagos Islands are not divided in their intimacy, as the affiliation is almost entirely with Mexico and Central America.

In the Hawaiian Islands, hydroid exploration has not been very intensive or extensive. Honolulu is advertised as the crossroads of the Pacific. As far as hydroids are concerned, it may be just that. The area seems to have obtained its species from all around the Pacific, with little sign of favor anywhere. A possible exception might be made of Japan.

The close affinity of the Siberian hydroids with those on the North American coast has already been noted. There are not so many species common to this region and the coasts of China and Japan as one might expect, but this may be from lack of records rather than lack of hydroids.

China and Japan have much in common and both of them have many species that occur farther south in the East Indies and Australia.

The Philippine hydroids are more commonly related to the hydroids of the East Indies and Australia. There are some in common with Japan, but it seems as though these came around through the China Sea or even through the East Indies rather than directly from Japan.

More species are reported in common in the East Indies and Australia than in any other two regions in the entire Pacific. There is a goodly number from both of these regions also common to China, Japan, and the Philippines. Australia has also much in common with New Zealand. Besides this association, New Zealand has little in common with any other region.

So few species have been reported from Polynesia (11) that there is almost no basis for comparison. The only indication of any association is with Australia. The same scarcity appears in the Antarctic regions contiguous to the Pacific. After the cosmopolitan species have been eliminated from consideration, practically nothing is left in common with any other region.

By taking these indications into consideration with oceanic features as shown by a contour map of the Pacific, some final conclusions may be justified.

Motive power in hydroids is distinctly limited. The scattering of one species in one area in one generation by the efforts of the individual members is almost infinitesimal. The free-swimming larval stage, the planula, exists as such for but a few hours or days at the most. Its ciliary movement is too weak to take it anywhere in particular. Even if the tide carries it away, it will probably carry it back again nearly as far. At the end of the short free-swimming stage it must become attached or perish. This means that it has little chance to survive in any large stretch of deep water. The shore and the shallow water over the continental shelf, with few exceptions, must be its habitat. Even here, since it has not power enough to cross a strong current, such a cross current might readily prove an effective barrier.

Where the species passes through a medusa stage, conditions for distribution are somewhat improved, but most of the hydromedusae are so small that they cannot travel very far. As this stage may last much longer than the planula, these medusae might get across a stretch of deep water if the conditions were favorable, but they would have little chance of stemming a strong cross current.

Most species of hydroids appear to be tolerant to not too great differences of temperature, salinity, and alkalinity, so that it is seldom that any of these differences will serve as much of a barrier to distribution.

In the contour map, then, a search must be made for ocean deeps and strong currents as the main interruptions to general distributional routes. There are but few of these. Off northern Chile an ocean deep comes near to the coast, and not far away the Humboldt Current, which has been nearly parallel to the coast, turns abruptly to the westward or northwestward, almost at right angles to the coast line. As previously indicated, this is the only effective barrier along the coast of America. Southeast of Japan there is an extensive deep that extends westward far enough to separate southeast Hondo from the Philippines. The effect on distribution here has been noted. Another deep separates much of New Zealand from Polynesia, but it does not extend far enough north to shut off Australia with the Norfolk and Kermadec islands from these Pacific islands. There is no pronounced deep between Japan and Hawaii, but of course the distance is great. With these exceptions there should be no pronounced barriers to distribution in the Pacific, along the continental shelf, and there appears to be none.

Finally, there is the matter of the actual distribution centers and distribution routes. This involves not only an examination of distribution in the Pacific itself, but also the distribution in all the other oceans, since they are definitely contiguous to the Pacific in some portion of its boundaries. Hence it is a very large question.

On previous occasions I have expressed my opinion on this matter as far as it affects most of the American coast. Stated briefly, it is that for many species in the North Pacific the center of distribution is in the North Polar region, from which center the distribution is at first circumpolar, and later down the continental shelf of each of the continents, the different species extending to different distances southward. From the previous discussion in this paper it would appear that this statement might be applied to the Siberian coast as well, and as far south as China and Japan.

Many other species on the American coast seem to have had their origin in the West Indian area, early enough to have unobstructed passage through the gap that at one time existed between North and South America. When through into the Pacific, they readily spread north and south along the coast as well as southeastward to the Galápagos.

I am not familiar enough with distribution in the rest of the Pacific, and the connecting parts of the other oceans, to venture an opinion concerning other distribution centers or distribution routes.

Summary

The exploration of so much of the expanse of the Pacific Ocean is so limited that while it is quite possible a fair proportion of the species of hydroids within its boundaries has been obtained, many of them have been reported from such a restricted area, often from a single location, that the data are insufficient to form a satisfactory basis for the study of distribution spread.

With the entire Pacific divided into fifteen large regions for comparison, of 1321 species reported from the whole ocean, only 350 have been reported from more than one of these regions. Much of the duplication is due to the presence of a comparatively few species, reported from five or more regions. With these eliminated from consideration, very definite affinities are shown for each region. These associations show that there may be free spread of distribution, everywhere in water that is comparatively shallow, as over the continental shelf, unless it is interrupted by strong cross currents. The only serious barriers, apart from those in midocean, are the ocean deeps near the north coast of Chile, between Japan and the Philippines, and between New Zealand and Polynesia.

The determination of distribution centers and distribution routes involves the examination of distribution in all other oceans contiguous to the Pacific. It has been attempted only so far as it affects the American coast.

THE MARINE INVERTEBRATE FAUNA OF THE CALIFORNIAN ISLANDS

By T. D. A. Cockerell

On San Miguel, San Nicolas, and San Clemente islands I found extensive deposits of marine shells of Pleistocene age. The species were very kindly determined for me by Miss Myra Keen. The lists for San Miguel and San Nicolas have been published in the *University of Colorado Studies,* Vol. 26, November, 1938, pp. 8–9. The San Nicolas list, as there given, included only the species found in the deposit near the top of the island. At various levels below this, down to near the shore, are deposits of shells, undoubtedly Pleistocene, but presumably for the most part having slid down the hill and not really belonging to their present apparent levels. Such deposits will also include land shells which come from the layer which, when in place, is always above the marine layer and entirely distinct from it. These shells on San Nicolas include the following species not listed in the paper referred to: *Miodontiscus prolongatus* (Carpenter), *Saxicava arctica* (L.), *Acmaea insessa* (Hinds), *A. scutum* Esch., *Bittium catalinense* Bartsch, *Conus californicus* Hinds, *Cypraea spadicea* Swains., *Mitrella gausapata* (Gould), *Nassarius mendicus cooperi* (Forbes), *Pseudomelatoma torosa* (Carp.), *Tegula montereyi* (Kiener), *T. funebralis* (A. Adams), and species of *Tritonalia* and *Semele.*

Along the shore at San Nicolas Island the following living species were obtained: *Chama pellucida* Sowerby, *Cumingia californica* Conr., *Hinnites multirugosus* (Gale), *Lucina californica* Conr., *Protothaca staminea* (Conr.), *Septifer bifurcatus* Conr., *Spisula* cf. *planulata* (Conr.), *Acmaea limatula* Esch., *A. digitalis* Esch., *A. mitra* Esch., *Crepidula nummaria* Gld., *Gadinia reticulata* Sowerby, *Littorina planaxis* Phil., *Lottia gigantea* Sowerby, *Norrisia norrisi* (Sowerby).

It will be seen that the recent species obtained are all different from the Pleistocene ones. Yet this does not indicate a very different climate. Miss Keen remarks that both Pleistocene lots indicate a slightly cooler water temperature than the collection of recent species, but this is only a matter of a few degrees and may be due to the fossil series being mainly from deeper water.

The San Clemente Pleistocene collection, obtained in May, 1939 (the collecting done with the assistance of J. T. Scott and Logan Buchart), came from near the middle of the island, at an elevation of somewhat over 800 feet. Miss Keen finds that it corresponds with the fauna of the Timm's Point bed on the mainland, as described by Alex Clark. The species are numerous, as follows: *Cardita ventricosa* Gld., *Crenella divaricata* (d'Orb.), *Epilucina californica* Conr., *Glycymeris septentrionalis* (Midd.), *Lucinisca nuttallii* (Conr.), *Mytilus californianus* Conr., *Psephidia* cf. *lordi* (Baird), *Spisula planulata* Conr., *Transennella tantilla* (Gld.), *Acmaea incessa* (Hinds), *A. mitra* Esch., *A. pelta* Esch., *A. scabra* (Gld.), *Amphissa versicolor* Dall, *Bittium eschrichtii* (Midd.), *B. rugatum* Carp., *Dentalium* cf. *rectius* Cpr., *Diala* sp., *Hipponix cranioides* Cpr., *Homalopoma carpenteri* (Pils.), *Lacuna* sp., *Littorina scutulata* Gld., *Mitrella carinata* (Hinds), *M. gausapata* (Gld.), *M. tuberosa* (Cpr.), *Nassarius fossatus* (Gld.), *Odostomia* cf. *stearnsii* D. and B., *Oenopota* sp., *Olivella biplicata* (Sby.), *Opalia chacei* Strong, *Polinices lewisii* (Gld.), *Tegula funebralis* (A. Ad.), *Tritonalia foveolata* (Hinds). The water temperature indicated is a trifle cooler than that of the San Nicolas deposits, but hardly enough to be really significant.

We must conclude from these observations that during part of the Pleistocene the three islands referred to were nearly under water, and that when this was the condition, the climate was not very different from that of the present time. That these islands were not wholly submerged is amply proved by the existing terrestrial biota, with its endemic species.

On the other hand, the fossil elephants on the northern islands appear to prove the existence, during part of the Pleistocene (apparently more recent than the marine beds), of elevated land which was continuous with the main land. The excessive abundance of individuals of land snails in the layer above the marine Pleistocene on San Nicolas suggests a moister period than the present, with more vegetation. This was, of course, long before the island had been denuded by the grazing of sheep.

We found no marine Pleistocene beds on Santa Catalina. There was a report of such near the top of Mount Orizaba, but in 1938 Dr. F. P. Shepard climbed up to the locality and found that the shells were *Pecten* (such as had already been recorded from Santa Catalina) of Miocene age. This occurrence is fully described by him in a paper about to be published. Although various Tertiary fossils (including a Sirenian lately discovered on San Clemente by Theodore Murphy, to be dealt with by Dr. C. Stock) have been found on the islands, all are marine, and we have no direct evidence concerning the Tertiary land biota, if there was any.

Considering the present marine invertebrate fauna, we find it to be a mixed lot, representing both northern and southern faunas. The records are largely derived from dredging in deep waters, and in fact we seem to know more about the fauna of the depths than that of the littoral zone. Undoubtedly a close study of the shallow waters and tide pools will yield much of interest. The region, especially the vicinity of the northern group of islands, is remarkable for the meeting and mixing of cold and warm waters, and is thus to be compared with the Galápagos Islands, so well described by R. C. Murphy in his *Oceanic Birds of South America*. There is evidence of changes, presumably often rapid, in the water temperature of single localities, and apparently this explains the remarkable observations of Dr. F. B. Sumner on the extraordinary ability of certain fishes, especially *Gillichthys*, to endure and adapt themselves to rapid changes of water temperature. Not all fishes can do this, as shown in a very remarkable paper by A. S. Jensen, just published in *Biologiske Meddelelser* (1939), on the behavior of cod. It appears that during recent decades the water on the Greenland coast has become warmer and the cod have gradually extended far northward of their former range. But in the last two years the cold water has returned and many dead cod have been coming to the surface. They not only cannot stand the cold, but at low temperatures they cease feeding.

No such effects have been observed about the Californian islands, but in southern California at certain times (as I once observed at San Pedro), warmer waters, coming from the south, bring vast numbers of dinoflagellates, mainly *Gonyaulax polyedra*, so that the sea is stained red and is brilliantly phosphorescent at night. At such times there is great mortality of vertebrates and invertebrates, their dead bodies being cast up on the shores. This mortality is ascribed to the clogging of the gills by multitudes of *Gonyaulax*, but it may be partly due to the poisons set free in the decay of the dinoflagellates, and even perhaps in part to the warm water itself, carrying less oxygen than the colder water.

It is at any rate true that the waters about the islands are remarkable for the mixture of northern and southern types of animals. I have made out lists of some which range northward and others which range southward. These lists could be greatly extended, but as given here, on the pages next following, they will suffice to illustrate the point.

Marine Mollusca Ranging Northward

Dall (1921) lists 2122 species (exclusive of Cephalopods and Nudibranchs) from the Pacific coast down to San Diego, and of these he classes 148 as "Arctic" and 291 as "Aleutian."

Pelecypoda

Nucula tenuis Montagu to Alaska
N. carlottensis Dall to Queen Charlotte Island
Nuculana penderi Dall to Queen Charlotte Island
Yoldia beringiana Dall to Bering Sea
Tindaria kennerlyi Dall to Alaska. A deep-water species
Pecten alaskense Dall to Japan
Musculus olivaceus Dall to Bering Sea
Crenella decussata Montagu to Bering Sea
Calyptogena pacifica Dall to Alaska
Lyonsiella alaskana Dall to Alaska, deep water
Axinopsis sericatus Carpenter to Aleutian Islands
Marcia subdiaphana Carpenter to Alaska

Gastropoda

Aeolidia papillosa L. to Alaska and Europe
Argobuccinum oregonensis Redfield to Bering Sea
Trophon staphylina Dall to Alaska
T. smithi Dall to Bering Sea
Leptothyra carpenteri Pilsbry to Alaska
Calliostoma annulatum Martyn to Alaska
Puncturella multistriata Dall to Aleutian Islands
P. cooperi Carpenter to Alaska

Amphineura

Ischnochiton interstinctus Gould to Aleutian Islands
Mopalia ciliata wosnessenskii Middendorff to Alaska
Katharina tunicata Sowerby to Alaska
Amicula stelleri Middendorff to Alaska and Kamchatka

BRACHIOPODA RANGING NORTHWARD

Terebratalia transversa Sowerby to Alaska
Terebratulina kiiensis Dall and Pilsbry to Japan
Frieleia halli Dall to Kamchatka

Marine Mollusca Ranging Southward

Dall (1921) listed 2122 species of Mollusca (excluding Cephalopoda and Nudibranchiata) from the Pacific Coast down to San Diego, and of these he considered 131 to be "Panamic."

Pelecypoda

Nuculana pontonia Dall to Peru
Crenella divaricata d'Orbigny to Panama and West Indies
Lyonsia nesiotes Dall to Magdalena Bay
Verticordia ornata d'Orbigny to Panama and Antilles
Chama pellucida Sowerby to Chile and Galápagos Islands
Pseudochama exogyra Conrad to Panama
Lucina aequizonata Stearns to Chile
Fragum biangulatum Sowerby to Panama
Diplodonta subquadrata Carpenter to Panama
Tellina panamensis Dall to Panama
T. declivis Sowerby to Panama
Semele striosa C. B. Adams to Panama
S. pacifica Dall to Acapulco
Corbula obesa Hinds to Panama
C. porcella Dall to Panama

Scaphopoda

Dentalium numerosum Dall to Panama
D. agassizii Pilsbry and Sharp to Panama

GASTROPODA

Glossodoris californiensis Bergh. Southern distribution unknown, but a southern genus
Mangilia lineolata Reeve to Panama
Admete microsoma Dall to Acapulco (660 Fath.)
Trivia radians Lamarck to Ecuador
T. solandri Gray to Panama
Coralliophila costata Blainville to Panama
Potamides sculptum Sowerby to Panama
Turritella mariana Dall to Panama
Polinices reclusianus Deshayes to Chile (Philippi)
Sinum pazianum Dall to Panama
Tricolia substriata Carpenter to Panama
Tegula mariana Dall to Peru
Calliostoma eximium Reeve to Mazatlan
Circulus cosmius Bartsch to Panama
Fissurella volcano Reeve to Panama

BRACHIOPODA RANGING SOUTHWARD

Platidia seminula radiata Dall to West Indies

ASTEROIDEA RANGING SOUTHWARD

Freyella insignis Ludwig to Panama

FISHES RANGING SOUTHWARD

Dr. Carl L. Hubbs, in a letter of April 12, 1939, writes concerning the island fishes: "There is a rather curious mixture of some northern species and some southern species which do not occur or are at least very much less common on the coast of the adjacent mainland. A few forms are known only from the islands, but whether these are actually restricted to them is not clear in all cases. Quite a number of tropical groups have given rise to a single, rather well-marked differentiate in Southern California, and many of these have been separated out as types of monotypic genera."

I have been struck by the absence of representative races of species at different depths or under different conditions about the islands. Fisher records, of starfishes, that *Poraniopsis inflata* (Fisher) has a race *flexilis* Fisher, confined to deep waters, 344 to 600 fathoms. It is significant that Hubbs writes that he has never found a single interspecific hybrid among the many thousands of fishes from our region examined, though such hybrids are not rare among the freshwater fishes of North America.

SHORE ISOPODS: NICHES OCCUPIED, AND DEGREES OF TRANSITION TOWARD LAND LIFE WITH SPECIAL REFERENCE TO THE FAMILY LIGYDIDAE

By Charles Harlan Abbott

Introduction

Among the animals of the intertidal zone, none are more favorable for study of the transition from marine to land life than the Isopoda. This is so because all gradations in isopods can be found from the strictly marine to the strictly land type, and because the Ligydidae, which are among the most conspicuous of intertidal animals, are almost exactly midway between aquatic and land animals.

The subject will be developed in this paper[1] by three methods:

1. A brief summary of points of structure and physiology of isopods enabling them to make the transition.
2. Notes on the ecology of representative marine isopods of several grades of transition.
3. A special report of studies, at La Jolla, California, on *Ligyda occidentalis* (Dana),[2] comparing the results with studies on this and related species which have recently been reported from widely scattered regions of the world.

Structure and Physiology of Isopoda

Among the Crustacea, essentially an aquatic group of animals, the Isopoda are conspicuous as the most successful group in adaptation to land life. Significant characteristics in this connection are:

1. The body is flattened dorsoventrally, enabling the animal to take refuge in crevices where the evaporation is not so great.
2. Respiratory appendages. Whereas in most higher Crustacea the gills are branches of the pereiopods, in Isopoda the pleopods (abdominal appendages) are used as gills. The chitin of the pleopods is thin enough to allow diffusion of gases. This method is still utilized in the land isopods where the inner branches (endopodites) of the pleopods are essentially like the gills of aquatic forms in both structure and function. The outer branches (exopodites) serve as gill covers, and the gills are in part kept moist by glandular secretions. Most of the truly terrestrial forms have developed a sort of primitive tracheal apparatus on the outer branch for breathing atmospheric air directly, but this is not true of the primitive Ligydidae, described in this paper (Stoller, '99).

One difference in the use of gills between aquatic and land isopods is quite conspicuous. In the aquatic species the gills are constantly waved forward and backward in the water. In the land species the gills are held close against the abdomen, with the outer branch covering the inner branch. This difference will be referred to in the discussion of *Ligyda*.

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[1] The studies here reported were carried on at the Scripps Institution of Oceanography of the University of California, La Jolla, Calif., the Puget Sound Biological Station of the University of Washington, Friday Harbor, Wash., and the Biological Laboratory of the Long Island Biological Association, Cold Spring Harbor, N. Y. I am indebted to the authorities of these laboratories for the opportunities presented. Dr. V. E. Shelford and Dr. H. E. Walter made valuable suggestions in the earlier work. Elizabeth Nichols Abbott assisted in the field observations on *Ligyda occidentalis*.

[2] In the use of the generic name *Ligyda*, instead of *Ligia* which is used in most of the papers quoted, I am following Mr. J. O. Maloney of the U. S. National Museum, who verified my identification in 1932.

Notes on the Ecology of Representative Marine Isopods of Several Grades of Transition

FAMILY IDOTHEIDAE

Pentidotea resecata (Stimpson). Eel grass isopod.

Pentidotea wosnesenskii (Brandt). Fucus isopod.

These two species were observed to be abundant at Friday Harbor, Washington, in the summer of 1915. Each occupied a distinct niche. *P. resecata* was found on eel grass (*Zostera marina*) and was light green, the color of eel grass. *P. wosnesenskii* was found on the belt of *Fucus evanescens* on the rocky shore and was dark green, the color of the fucus. The fucus habitat was exposed at low tide more than the eel grass habitat.

Comparative experiments indicated that consistently the fucus isopod was able to endure more variations in environmental conditions than the eel grass isopod. This is shown in table 1. If we consider *P. resecata* as typically marine, *P. wosnesenskii* represents one step toward life out of water and tolerance of more extreme and varying conditions.

TABLE 1

Survival under Unfavorable Environmental Conditions of Pentidotea wosnesenskii (Fucus Isopod) and P. resecata (Eel Grass Isopod)

	P. wosnesenskii	*P. resecata*
Resistance to high temperatures		
1st Exp. Temp. at death	32°–35° C.	30°–31° C.
2d Exp. Temp. at death	33°–34°.5 C.	29°–30° C.
Survival time in fresh water. Average		
1st Exp.	150 min.	60 min.
2d Exp.	210 min.	83 min.
Survival in concentrated sea water. Average		
2 × normal concentration	266 min.	79 2/5 min.
1½ × normal concentration	4320 min.	445 min.
1¼ × normal concentration	2820 min.	1980 min.

FAMILY SPHAEROMIDAE

The members of this family are characterized by the habit of rolling in a ball (whence their name), which is commonly associated with certain genera of land isopods (Family Oniscidae). In both groups it is used as an adaptation for meeting unfavorable conditions.

Thorough studies of the ecology of this family being lacking, the following notes will be of interest.

a) *Sphaeroma quadridentatum* Say. This species was observed at Cold Spring Harbor, New York, in the summer of 1912. It was found in two tension-zone spots. One of these was the sea wall by the Biological Laboratory, fronting on the inner harbor, which is a mud flat at low tide bordering an estuary. At low tide, these isopods could be collected from wet crevices in the sea wall. The other location was in the estuary itself, on submerged logs, far enough up the stream so that the water appeared nearly fresh at low tide.

The ability to survive a dilution with fresh water was also experimentally tested by keeping individuals of this species in a small bowl of water on a laboratory table. The bowl contained sea water, diluted with about 25 per cent of fresh water. The individuals survived, and in experiments on sensitivity to contact showed normal reactivity. The species was particularly easy to keep under laboratory conditions.

b) A species of this family similar in size to *S. quadridentatum* was found one day in 1915 at Friday Harbor, Washington, under loose stones on the northwest cliffs of Brown's Island at low tide. Further search on subsequent days failed to find more individuals and the species was not identified. The fifteen specimens collected were used in comparative experiments with the two species of *Pentidotea* previously described. They survived temperatures of 34° to 36° C., which was higher than the *Pentidotea* species, and survived in fresh water for 40 hours in contrast to 1–3 hours for the fucus species and one hour for the eel grass species. The development of resistance in this species, which is often left out of water between tides, is comparable to that of *Sphaeroma quadridentatum* described above.

c) A small species, *Exosphaeroma oregonensis* (Dana) is left by the waves at La Jolla in very shallow pools either on the sand or on flat rocks. It is active in these pools and appears adapted to a difficult and very temporary habitat. The details of its behavior have not yet been investigated.

d) *Sphaeroma pentodon* (Richardson) was found by the writer as described by Johnson and Snook (1927, p. 287): "At Chula Vista Wharf, San Diego Bay, it may be found in holes in the hard adobe-like mud at the high tide line. The holes are from 6 to 13 mm. deep and the animals are found curled up at the bottom of them." Barrows (1919) found this species in burrows in soft sandstone on San Francisco Bay, and mentions the variations in salinity of the habitat, at times the water being nearly fresh.

e) Pearse (1936, p. 25) tabulates a study by Schliënz (1923) on distribution of marine animals in the Elbe River near the mouth. It showed that a species of *Sphaeroma* ranged considerably higher than two species of *Idothea*. The minimum salinities in which they were found were: *Sphaeroma rugicanda,* 5.90; *Idothea viridis,* 13.15; *I. baltica,* 15.36. Pearse also summarizes: "Prenant (1929) has called attention to the fact that the distribution of marine species in estuaries is correlated with respiratory requirements. As water becomes less saline, respiration becomes more difficult."

f) Chilton (1925), in New Zealand, described a species of this family, genus *Paravireia,* in a fresh-water stream, a few hundred yards from the ocean but living entirely in fresh water. He believes it a very old species which has survived owing to the adoption of a fresh-water habitat.

g) Richardson (1905) records *Exosphaeroma thermophilum* (Richardson) from a warm spring in New Mexico.

h) Arey and Crozier (1919) record a commensal *Sphaeroma* which lives under the shell of a chiton, at Bermuda.

These instances show Sphaeromidae in process of conquering a variety of habitats, with particular success in becoming adapted to fresh water.

FAMILY LIGYDIDAE

The isopods of this family, while structurally classified as land isopods, are found only close to the water's edge at the seashore. They are world-wide in distribution, rather conspicuous, but only recently has their ecology been extensively studied.

1) The basis of this discussion will be a summary of a study made by the writer in 1932 and 1933 of the species *Ligyda occidentalis* (Dana) at La Jolla, California, on the beach and rocks near the Scripps Institution of Oceanography. An analysis of its behavior was given before the Western Society of Naturalists at La Jolla in 1934 (Abbott, 1934). The following facts then presented have a bearing on the present discussion.

a) The normal habitat of *L. occidentalis* is above the water's edge, from about the 3-foot tide level or slightly lower to the cliffs a little above the highest tides.

b) These isopods may be found at the water's edge or higher up; they run about on the rocks or feed on minute moist particles on the surface, even in bright sunlight; at other times they collect under stones and masses of the seaweed *Macrocystis pyrifera;* they can be seen climbing the rocks ahead of the waves; they sometimes feed under water in tide pools; but there is no evidence that they stay to be submerged at high tide.

c) These isopods are particularly numerous at night, when they can be seen emerging at dusk from crevices in the wooden sea wall; after which they are abundant both there and widely scattered on the beach. The humidity of the beach is notably greater at night as shown by the fact that water then stands in depressions on the sand.

d) The pleopods are used for both atmospheric and aquatic respiration. In the air the gills are held close against the abdomen, the outer branches keeping a moist film over the inner branches. In water, the outer branches are raised and the inner branches are waved constantly, as is characteristic of *Sphaeroma* and other marine forms. Thus in the use of its gills this species conforms to its location, whether in air or water.

This isopod is very active on land, but comparatively inactive in water. Its normal life and activity is that of a land animal.

e) The reaction to water is particularly interesting. On approaching a tide pool, *Ligyda* tests the water with its antennae, then turns around and comes to rest with the uropods and sometimes the tip of the abdomen in the water. As far as one can see, both at tide pools and in experimental tests in the laboratory, the uropods when placed together form a capillary tube for drawing up water to moisten the gills. Opposed to this, an isopod when emerging from a tide pool pauses at the edge and repeatedly raises its abdomen in a movement which appears to remove excess water from the gills.

If an isopod is held in the hand, the film of water covering the gills can be readily seen, and it is moved back and forth over the gills in what resembles a peristaltic wave.

The nervous mechanism involved in making this isopod seek the water and making it stay near the water has not been determined. There seems to be some kind of a responsiveness to moisture which overcomes any counterinfluence of light or gravity.

f) Laboratory experiments indicated that *L. occidentalis* will survive over 24 hours in unchanged sea water. In running sea water they were apparently normal after 6 days. On dry sand, young *occidentalis* just out of the brood pouch, succumbed in 1–2 hours, but adults survived considerably longer.

The following hypothesis is suggested. These isopods gradually move down the shore at ebbing tide because only so are they near enough to water to satisfy their moisture requirements. A positive reaction to moisture (hydrotaxis) results, at least at times, in a traveling toward a body of water until some part of the body is in actual contact with water. Their behavior mechanism discriminates between slight differences in moisture.

The fact that all individuals do not respond at each low tide may be due to the different conditions under which they happen to be at the time. If they are sheltered in the crevices of cliffs or under a damp mass of *Macrocystis pyrifera,* they are in a region of sufficient moisture. If, however, they are in dry situations, or come out on top of the rocks, their positive hydrotaxis draws them toward the water.

It may be noted further that the vertical sides of the ledges, the only exposed places where isopods are abundant in the daytime, are usually less exposed to the direct rays of the sun and are consequently more damp than the flat tops of the ledges.

This reaction is adaptive also in bringing these isopods to sources of food, either moist organic particles on the rocks, and sometimes at least the coating of tide pools, or damp *Macrocystis* fronds. Observations and experiments endeavoring to test the influence of light and gravity give conflicting results. If there is a definite reaction to these factors, as is true for light in the strictly land isopods (Abbott, 1918), their influence is subordinate to humidity and food. In a study of the pulmonate *Onchidium,* which is found in the same kind of habitat, Arey and Crozier (1921) found the negative light reaction subordinate to other factors in determining the normal behavior of the animal.

2) The species *Ligyda pallasii* (Brandt) was studied by the writer at Friday Harbor in 1915 and its general behavior coincides with that of *L. occidentalis* (Abbott, 1918). Experiments indicated a longer survival in dry air and a shorter survival in sea water, but the experiments were not entirely comparable. In fresh water it survived longer than the strictly marine forms, but not so long as the representative of the Sphaeromidae.

3) Miller (1938) included the two species of *Ligyda* here described in his recent comparative studies of terrestrial isopods of the San Francisco Bay region. In his case, *Ligyda* was the most marine of his terrestrial series, so that his paper supplements rather than parallels the present discussion. The most important point applicable to the present paper is that he demonstrated that several land isopods react in a humidity gradient positively to the higher humidity. *Ligyda* was not included in this experiment.

4) *Ligyda baudiniana* Milne Edwards. The most complete study of another member of this genus is that reported by Barnes (1932, 1934, 1935) on *L. baudiniana* at Bermuda. Comparing his results with those in this paper, the species he studied seems to occupy almost exactly the same niche as *L. occidentalis.* Apparently *L. occidentalis* is slightly more aquatic, since he says that *L. baudiniana* never stays submerged. However, he qualifies this by showing that the species he studied can endure prolonged submersion in sea water, and that the young are more aquatic than the adults, which agrees with the observations of *L. occidentalis* at La Jolla. Barnes describes similar uropod reflexes for maintaining the right degree of moisture on the gills.

5) *Ligyda exotic* (Roux), as reported from Japan by Numanoi (1934) and Pearse (1936), also appears to occupy the same niche as *L. occidentalis.* Numanoi (1933*a*) showed a definite relation of rate of beating of pleopods to an increase of temperature from 6° to 30° C. Above 30° the beats were too rapid to count. He found a similar relation in the fresh-water Asellus (1933*b*).

6) According to Barnes' summary (1932, 1934) *Ligyda oceanica* (Linnaeus) of the British Isles, studied by Tait (1917) and Nicholls (1930–31) is definitely more aquatic than the other species of the genus here described. It "sometimes remains covered with the tide," it "may live over eighty days in sea water"; in diluted sea water it survived "as long as forty days in 50 per cent sea water and ten days in 25 per cent sea water." The rate of beating of pleopods increased in diluted sea water, which Barnes also reported for *L. baudiniana* (1934). On this last point, Barnes concludes: "The increased gill frequency (in dilute sea water) can be interpreted in terms of Schlieper's (1929) theory as a means of providing the extra oxygen necessary for work performed in the temporary resistance to osmotic forces."

Nicholls (1930–31) reports that *L. oceanica* is nocturnal and never appears in the day except when disturbed. At night, they feed on the sea wall, as described above for *L. occidentalis,* but the light of a bright moon keeps them from emerging. Very young individuals sometimes appear in the daytime.

To summarize the work on the Ligydidae from the Pacific Coast of North America, Bermuda, Japan, and the British Isles, the members of this family are as a family and as species widely distributed over the seashores of the world. In all cases they occupy essentially the same niche, that of the most primitive family of land isopods, which can live only close to the edge of the ocean and survive limited times in sea water.

There are some slight variations in degree of adaptation to land. From the data for three species, for which comparative data seem to be available, *L. oceanica* of the British Isles appears the most aquatic, *L. occidentalis* of our California coast intermediate, and *L. baudiniana* of Bermuda the most terrestrial.

In contrast to the Sphaeromidae, the Ligydidae occupy one large niche rather than a variety of smaller niches.

CONCLUSIONS

On the Pacific Coast of North America, and comparably on other ocean borders of the world, we find in the order Isopoda of the class Crustacea all the gradations from marine to land life. The structural modifications are few, but there is an adaptive physiology and behavior. The marine forms show adjustment to variations in salinity, the intermediate forms show a controlling influence of humidity. The study gives concrete form to the common observation that the seashore represents a tension zone between ocean, fresh water, and land, and is a point of divergence between related species.

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A THEORETICAL DEFINITION OF PRODUCTION

By Marston C. Sargent

Since Hensen, nearly fifty years ago, began the systematic investigation of the production of the sea, a great deal has been added to the theoretical foundation of the investigation, while comparatively little has been accomplished in the direction of bringing the investigation to a successful close. A further addition to the body of theory can do no harm.

The production of a portion of the sea during a given period can be theoretically defined as the number of calories of solar radiant energy converted into chemical potential energy in that portion of the sea during that period. This definition says that a phytoplankton crop is measured not, for instance, by the number of cells, or their dry weight, but by their heat of combustion. Restated in other terms, production (or we can call it yield) is measured by the amount of oxygen evolved by the process of photosynthesis carried on by plants. This definition merely repeats in physical and chemical terms that the whole photosynthetic activity of green plants and this alone constitutes the production of the sea. While most of the energy stored in the sea by plants is dissipated in ways that we might call useless or unproductive, in a humanistic sense, nevertheless this quantity of energy originally stored is the quantity we must start with when we begin to reckon the actual or possible production at some higher biological level.

There are some small discrepancies and ambiguities in the definition of production as given above which must be cleared up. If production (i.e., photosynthesis) is measured by estimating oxygen evolution, an error is introduced by the fact that a small amount of oxygen is evolved by the process of nitrate reduction and sulphate reduction. The amount of oxygen evolved by nitrate reduction in green plants has been measured and found negligible as compared with the amount evolved by carbon dioxide reduction. The amount of oxygen evolved by sulphate reduction in green plants is so small that it has never been measured. Another difficulty arises from the fact that green plants carry on respiration as well as photosynthesis, and the respiration is exactly equal to and exactly undoes a certain amount of photosynthesis. The respiration which is supposed to occur simultaneously with photosynthesis need not concern us, because it never appears in any measurement. However, the respiration which occurs in plants while they are not carrying on photosynthesis, that is, at night, has the effect of making the production during a period ending at nightfall larger than the production on the following morning. Every night, some of the energy previously stored by photosynthesis is dissipated by respiration. In high latitudes and in winter this effect may be important. However, if we consider production during a minimum interval of 24 hours, it will be independent of the hour at which the period began.

The only excuse for this theoretical definition is that it may be of some assistance in the practical measurement of production. Up to date, three principal methods have been used for the practical estimation of production. One method consists of taking a census of the phytoplankton population either once or at intervals. The population may be enumerated, cell by cell, or it may be weighed, wet or dry, or it may be estimated from its content of some constituent, such as the acetone soluble pigments. It is clear that a single census gives no information about production, because production, by any definition, depends on rate of change of population, which may actually be independent of size of population. However, by analogy with crop plants a pair or a series of censuses might yield information about production. If the population is found to be small on a given date and larger on some subsequent date, the difference might represent the amount of production between the two dates. This would be true if the population were subject to no attrition in the interval. But if the population were not subject to attrition we would not be interested in it. Only because the phytoplankton organisms are continually being consumed are they of importance in the picture of production. And as long as they are continually consumed, the difference between the counts on any two days is no measure of the number produced in the interval. Besides these, so to speak, swivel-chair objections, the methods of taking censuses have been subject to numerous practical criticisms. These have to do principally with the methods of collection, the errors of estimation, the proper weighting of samples, and the choice of stations. Most of the criticisms have been met, or can be met, in the actual collection of data for the solution of a given problem. If they are met, and if the data are interpreted in connection with information of a kind to be described below, the method of taking censuses becomes one of the most important tools in estimating production.

The second method used for estimating production involves the measurement of changes in the sea water which can be correlated with the activities of phytoplankton. For instance, increase in alkalinity during an interval has been used as a measurement of the carbon dioxide removed by photosynthesis. The decrease in dissolved phosphate has been used in estimating the increase in phytoplankton. In principle, the difference between this method and the first is that the quantities measured are more stable than the quantity of phytoplankton. A portion of the phytoplankton produced during a given period may have disappeared during the period by being eaten or by meeting other lethal conditions, and hence never appears in a census taken at the end of the period. However, the phosphate removed from solution by this portion of the phytoplankton is not, in general, returned immediately to the soluble condition, but remains out of circulation for a period, perhaps as long as a month, according to experiments by Cooper (1935). If phytoplankton always contains a fixed proportion of phosphorus, the quantity of soluble phosphorus disappearing from the sea during certain brief intervals can be considered a satisfactory measure of the phytoplankton production during those intervals. However, over long periods the regeneration of soluble phosphate impairs the accuracy of the estimation, and for any period beginning at a time when regeneration is already well established, changes in phosphate concentration may be quite independent of production. The estimation of production from observations on changes in the oxygen content or the alkalinity of sea water is similarly limited by the fact that these quantities are subject to alteration through exchange between the water and the atmosphere.

The third method of estimating production was introduced by Gran (1927). Essentially, this method consists of enclosing a representative sample of the sea and measuring the oxygen evolution in the sample during an interval. When properly controlled, this method corresponds exactly to the estimation of production as defined in the opening paragraph. Any bottle of raw sea water collected directly without the use of a net can be expected to contain a reasonably representative population of local phytoplankton, if we assume that in a restricted portion of the sea there are no gross inhomogeneities in the distribution of phytoplankton. Such a bottle will, in general, contain zoöplankton, although the degree to which the zoöplankton population is representative is open to question.

In a bottle filled with a pure culture of diatoms, the measured oxygen evolution during 24 hours is proportional to the production. If a bottle also contains zoöplankton, or any heterotrophic organisms, the measured oxygen evolution is less than the amount which measures production by the amount which is consumed in the respiration of the zoöplankton. The respiration of the zoöplankton depends only on the number (or mass) of these organisms present, and over a period as short as 24 hours can be considered constant. Consequently, if the zoöplankton can be separated from the phytoplankton by filtering or otherwise and its oxygen consumption measured, this quantity can be added to the measured oxygen evolution in the bottle of mixed plankton to obtain the amount of oxygen actually set free by the phytoplankton in the interval. In periods of bright sunshine, and long days, the estimate obtained by adding to the reading of a bottle of mixed plankton kept under natural illumination for 24 hours the reading of a similar bottle kept in the dark for 24 hours would be sufficiently accurate because the rate of plant respiration is ordinarily no more than one-twentieth the maximum rate of photosynthesis.

When a sample of raw sea water is confined, it is notorious that, from the biological point of view, it soon loses many of the properties of sea water in the sea. Whatever population it contained when it was first caught, is replaced, after a few days or weeks, by a new population, usually composed of species seldom found in numbers in the open ocean. The basic aspect and causes of this change will not concern us here, but the result is that measurements of production as outlined above cannot be carried out over long periods. Experiments lasting 24 hours are not liable to large errors from this cause.

The most serious error in this method arises from the difficulty in obtaining a sample of water which contains a representative zoöplankton population. How great this error is can only be determined by extensive and careful experimentation. It might even turn out that the method is unworkable on account of this single difficulty.

Supposing for the moment that this unhappy possibility can be avoided, the measurement described gives an accurate picture of production. Compare a measurement of this kind with a measurement obtained from two censuses. If there are no grazing organisms present, production during the interval studied will be reflected in the increase in phytoplankton population. If there are many grazing organisms, there may be a very small increase in population, even in the face of considerable oxygen production, as pointed out by Harvey, Cooper, Lebour, and Russell (1935). If there is no regeneration of phosphate, the production can be measured by the disappearance of phosphate, but if active regeneration is occurring there may be no measurable change in phosphate concentration during an interval of active oxygen evolution. The oxygen evolution alone can be considered an accurate measure of production.

Measurements essentially like the ones proposed were carried out successfully over a period of a year by E. Steeman Nielsen (1937) at one station in waters near Copenhagen. Because the station was quickly and easily accessible it was possible to make measurements at intervals of a week. If it is desirable to make an extensive series of observations over a large area, this method becomes cumbersome. However, when used in conjunction with this method, the method of taking censuses can give a reliable estimate of production. The rate of production is clearly a function of population, and if both quantities are measured at intervals (of both time and space) the production can be estimated from population measurements alone, taken at smaller intervals. By this combination of methods a reliable picture of production over large areas and long periods should be attainable.

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RIVER DISCHARGES AND THEIR EFFECT ON THE CYCLES AND PRODUCTIVITY OF THE SEA

By Emil Liebman

It is generally agreed that the high fertility of the coastal areas of the sea is largely due to the fresh-water sources coming down from the continents. Despite its importance, this problem has not hitherto received sufficient attention, though it is evident that among the external nutrient sources of the sea—such as rain and melting water from the polar regions—water coming down the rivers is richest in nutrient matter.

Atkins (1923), examining the phosphate contents of fresh and salt waters, found but very little influence of river discharges in Plymouth Sound. He admits that the phosphate content of the English rivers examined is much lower than that found by McHargue and Peters (1921) in the Mississippi and other large rivers of America. This of course may largely be responsible for the lack of influence in Plymouth Sound. In a later paper (1926) he, and in the same year Harvey, again found practically no influence in these regions. Finally, in his book on the *Biological Chemistry and Physics of Sea-Water* (1928), Harvey maintains that the nutrients of the rivers around Plymouth are consumed by the plants growing in the tidal and nontidal zone. But both he and Atkins (in his first paper) infer that conditions with regard to large rivers may be quite different.

A much more outspoken opinion on the relationship between rivers and sea is held by Hesse. He considers that the wealth of life in the coastal waters depends—in addition to the extent of shallow areas—on the amount of fresh water discharged into the sea. He goes even further in this belief and suggests that the high fertility of the Atlantic and Arctic is due to the fact that they receive the drainage of more than half the earth's surface, while the Pacific gets only about 27 per cent. Hence, in his opinion, the latter is much poorer in nitrates than the Atlantic or Indian oceans. Even in the Pacific he finds that while the western part, advantaged by its well-developed shallow coast and supplied with the discharges of the great Asiatic rivers, is one of the richest areas in the world, its southeastern part is one of the poorest, owing to the steepness of the American coast and the complete lack of large rivers.

Now I wish to outline my own observations on the Nile's influence on the Eastern Mediterranean and those on the influence of the Mississippi on the Gulf of Mexico recently published by Riley (1937). These two rivers may well be compared, both in regard to size and the nature of their waters, and they present similar pictures in their influence on the sea.

Before describing the effects of the Nile on the Eastern Mediterranean coast, it is necessary to give a very brief outline of conditions prevailing in these parts of the sea and a description of the Nile (fig. 1).

The southeastern part of the Mediterranean is the warmest part of this sea: surface temperatures reach 30° C. in August, while the deep waters (1000 m. and over) maintain a constant temperature around 14° C. Salinity is also very high and reaches 39.1‰ at the surface during the middle of the summer, while the deep sea shows a salinity of 38.7‰–38.6‰.

Both the high salinity and temperature are the results of the climatic conditions of these regions: the short winter is cool and rainy, the minimum temperatures fall in January and February, but the spring, summer, and autumn are dry and hot, the maximum temperature occurring in August. The southern part of the eastern Mediterranean is practically rainless throughout the year, while the eastern shores get most of their rains during December, January, and February. Consequently, all the rivers, with the exception of the Nile, have a high water discharge during the short rainy period only, while during the remaining three-quarters of the year the smaller dry up entirely and the larger have but a very insignificant flow.

The eastern part of the Mediterranean is fairly stormy during the greater part of the year; the second half of the summer and the early autumn are the quietest periods. In this region a current runs along the coast in an anti-clockwise direction; this is a part of the greater system running in this direction from the Atlantic through the Strait of Gibraltar on the periphery of the Mediterranean. This current is of great importance for the distribution of the Nile waters, as will be stressed later.

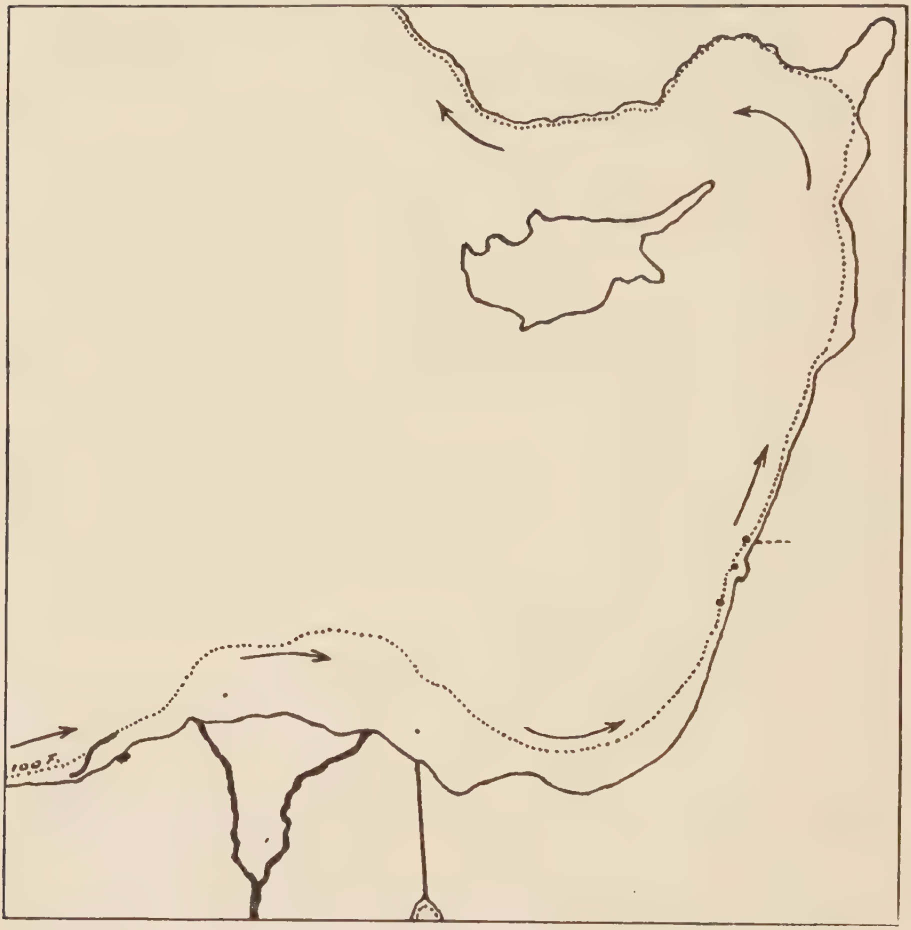

Fig. 1. The Eastern Mediterranean, showing the Nile Delta and the eastward-flowing current in the Sea.

The largest river of this region and of the Mediterranean as a whole is the Nile. At a considerable distance from the sea it forms a delta and discharges its waters through two arms which are about 150 km. apart at their entrance to the sea. Partly owing to human interference, its water discharge is very irregular and entirely different from the pattern outlined above for all the other rivers of this region. Following the heavy spring rains in Abyssinia, the flow of the water into the sea is greatest from August till November, but decreases toward the end of the latter month, giving place to a normal flow which lasts from December till the end of February. But at the beginning of March earthen dams are built at both arms of this river for irrigation purposes and the barrages are tightly closed so that no water enters the sea from March till the end of July. Toward the end of the latter period the level of the river rises continuously. At the end of July, when the water has risen by some 25 feet owing to the tropical rains, the barrages are opened and great amounts of water rush into the sea. The dates of the opening of the barrages have been registered for years and usually occur during the first days of August.

We therefore have three distinctive periods in the water discharge of the Nile: (1) the normal, lasting from December till February—3 months; (2) the period when discharge into the sea is nil—from March till the end of July, and (3) the period of maximum discharge, beginning in August and passing into the normal flow in December. It is evident from this description that the flow of the Nile is entirely different from that of all the other rivers in this region, its maximum flow falling into a sea which for months has received no fresh-water discharge whatsoever.

I should like to emphasize the seasonal fluctuation in the flow of the Nile water, as it gives an opportunity of studying the conditions in the sea with and without the fresh-water factor and provides in some way an experiment with a control test. This may well be a rare situation in which our problem can be studied in so favorable a way.

As to the effect of the Nile flow on the Egyptian coast, there are no direct observations except the few made by Steuer (1935), which I will mention later. But the location of the fishing grounds, the return of the fisheries in general, and the movements of the sardine shoals follow so closely the fluctuation of the Nile that they are undoubtedly a result of the changes in fertility of the sea brought about by it.

The two richest and most frequented fishing grounds in this area lie at a distance of 15–20 miles from each of the Nile effluents in a northeasterly and an easterly direction, respectively. The current running east, mentioned above, diverts the Nile discharge in this direction so that the position of the fishing grounds is a product of two components: one, the river flow; the other, the sea current. The more we move away from these two centers the poorer the fishing grounds become and the less frequented by the fishermen.

The fisheries returns for this region show a marked increase in catches during the high run of the Nile water, but the picture with respect to the migration of sardines is particularly impressive. The species inhabiting this area are rather euryhyaline, living close to the shore and frequently entering estuary waters. During the months when there is no Nile flow, they are very scarce on the Egyptian coast and the returns are the lowest of the year; but with the beginning of the Nile flow and the ensuing great development of plankton in the sea, they gather in these regions in immense numbers and form big shoals. The amount of sardines caught during the three months following the opening of the Nile barrages amounts to more than 80 per cent of the year's catch. And the average monthly catch during this period is usually 50–70 times as high as the average of each preceding month, when there is no Nile flow whatsoever. Furthermore, the dams on both arms of the river are not opened simultaneously and sometimes a period of two weeks elapses between the two. In this event, the sardine shoals appear in front of that arm which was first opened, and the fisheries start earlier here. The fishermen, by the way, well know that the sardines are attracted by this flow of the Nile, and they proceed accordingly.

Thus so far as the conditions along the Egyptian coast are concerned.

But the influence of the Nile flood is felt in far more distant waters, as may be learned from the investigations which I conducted during a period of two years. These investigations were carried out at three points around Haifa Bay on the eastern Mediterranean coast, which are at an average of 500 km. distant from the Nile Delta as followed along the coast and 420 km. as the crow flies. These investigations, though primarily intended to discover the underlying reasons for the very marked seasonal migration of the coastal fishes, gave very interesting results on the influence of the Nile upon these far-removed shores.

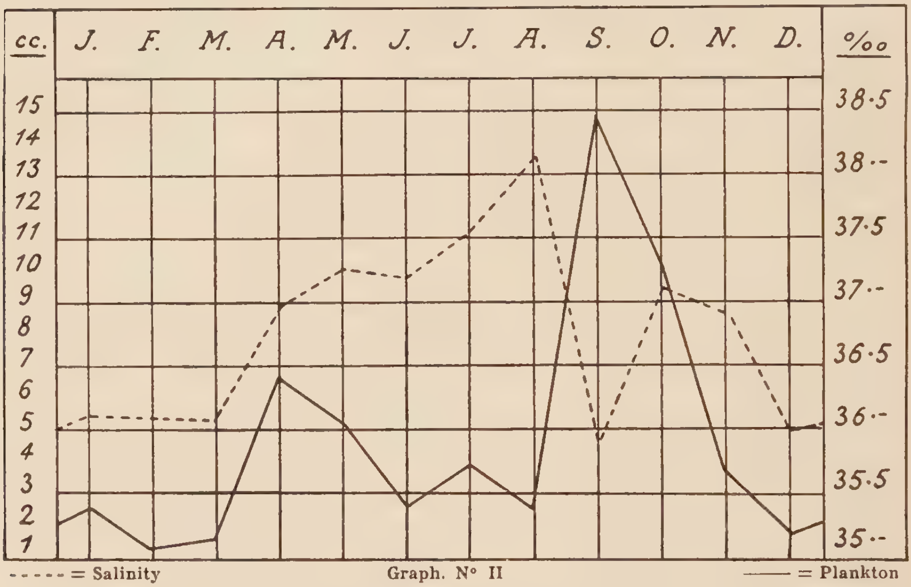

Fig. 2. Salinity and plankton distribution 4 to 6 km. from the shore of the eastern Mediterranean.

The investigations were conducted at weekly intervals as far as weather conditions permitted and were carried out at a distance of 4 to 6 km. from the shore. At every trip the temperature and salinity of the surface water were determined and the plankton of a 25-m.-deep column of water collected. For the latter purpose I used a medium-sized quantitative Hensen-Apstein net of the finest bolting silk, No. 25. To prevent decay the catches were formalinized on the boat and, when brought to the laboratory, were transferred to measuring cylinders and left to settle for a week and then recorded. This method gives sufficiently accurate results for a comparative study of seasonal plankton fluctuations in a certain area, provided the same type of net is used throughout the whole period of investigation as well as the same method and time of sedimentation. These rules were strictly observed during the entire period of my work. The result of these investigations with respect to the salinity and plankton distribution is shown on the graph (fig. 2). The salinity is fairly low from December till March, owing to heavy rains and river discharges and the relatively low temperature prevailing at this time of year. But with the rains over in March, and the temperature increasing steadily, a parallel rise in salinity of the surface water is noticed. This goes on with a small break in June till it reaches its peak in August, the hottest month of the year. Henceforth, instead of increasing further, or at least remaining stable as one would expect for all objective reasons, it suddenly drops at the end of September to an even lower level than during the winter months. This great drop in salinity can be emphasized even better when we consider the absolute maxima and minima observed. While the minimum salinity recorded during the rainy winter in the two years of observation was 35.48‰, the minimum salinity observed at the end of September was 34.02‰. Salinity remains relatively low during October and November, till it falls to a new low level in December with the onset of the winter rains.

It is evident that this sudden drop in salinity during September, October, and November cannot be attributed to climatic conditions prevailing in this or the surrounding regions. Rains have ceased since March and the rivers have dried up completely, the few bigger ones having reduced their output to a minimum. Neither is there any indication that this sweeter water may have risen from greater depth by upwelling, even if we overlook the fact that water of such a low salinity can hardly have its origin in deep strata. This excessive drop in salinity of the sea water in these regions at this time of year is due to the great influx of fresh water from the Nile, beginning in August. These waters are carried along the shores by the current, first toward the east and then to the north. There is no question of any near-by river's influx at this time of year, as they are all dried up along the whole coastline between the Nile Delta and the points of investigation.

The Nile flow has also a great influence on the plankton growth of this area. The plankton of the Mediterranean as a whole is quantitatively poor and its southeastern regions are particularly poor. The graph shows the relative seasonal abundance in the upper 25 meters of the shore region. It shows a distinctive spring maximum in April with a slight decrease in May, but falls again to a very low level in June, July, and August; however, in September and October, coinciding with the sharp drop in salinity, it rises to heights far exceeding the spring maxima—an average of 15 $cm.^3$ per haul in September against 6½ cc. in April. Even more impressive are the absolute maxima of 30 $cm.^3$ and 35 cc. in September and October against 12½ cc. observed in April. At this time it is a monotonous chaetoplankton composed of a few species with very little zoöplankton. Its abundance is so great that every haul of the net from the relatively small column of 25 m. fills the bucket entirely. Furthermore, as a result of this extraordinary abundance of phytoplankton the coastal water of the whole southeastern Mediterranean changes its color from a dark blue to grass green, a color which is very rare in this sea and does not even occur during the spring maximum. This luxurious plankton growth coinciding with the greatest discharges of the Nile is brought about, or at least greatly augmented, by the nutrient matter which this river carries into the sea. Steuer (1935), examining the fishing grounds near Alexandria, on the western fork of the Nile, also met this extraordinary growth of plankton, and the quantities found as well as the seasonal distribution show great similarity to those observed by me. According to his observations, this abundance first develops in the harbor and very close to the coast, but with the increase of the Nile flow it moves seaward to the edge of the continental plateau.

The increase of plankton in the areas investigated attracts schools of fish as well as other forms into the shallow shore region. During the hot summer months these waters are practically devoid of life, but with the advance of the fresh water and the increase of plankton great shoals of migratory fish appear actually overnight along the Palestinian and Syrian coasts; the sea begins to teem with life and the fisheries enter upon a very productive period. This is the economic phase of the problem.

In summary it may be stated that the discharge of the Nile has a great effect on the productivity and life cycle of a great portion of the southeastern Mediterranean. According to Steuer, this influence extends some 30 km. west of Alexandria; but the current carries the Nile waters east and north, where they are still noticeable at 500 km. from the center of the Nile Delta. Altogether, this comprises a coast line 650 km. in length. But judging from the intensity of this influx at the northernmost point investigated, it may be surmised that this influence is effective farther north on the east Mediterranean coast. Unfortunately, there are no observations of this kind from the northeastern part of the Mediterranean along the Syrian and Turkish coasts.

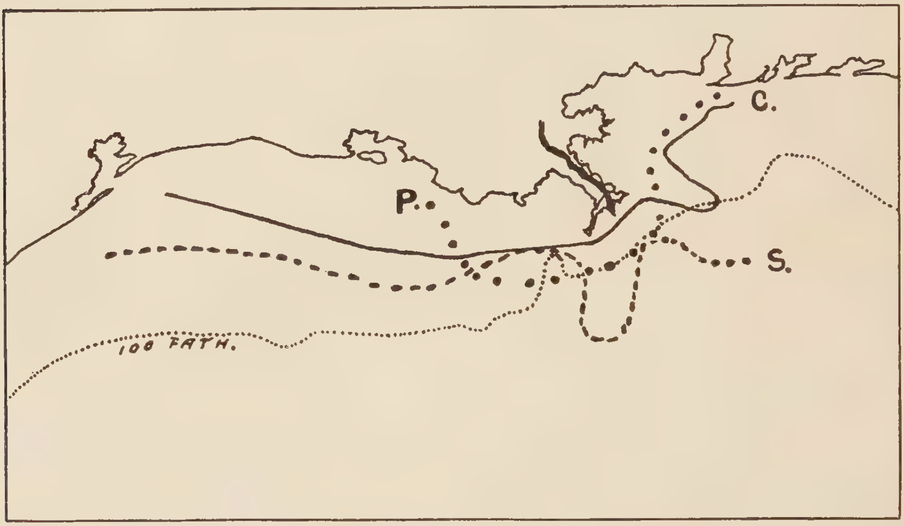

Fig. 3. Range of influence of the Mississippi River's discharge with regard to: S, salinity (35‰–10‰); C, plankton (chlorophyll 7.5–11.1 H.U.); P, phosphates (6–16 mg. per m.^{3}). After Riley.

As to the width of the area influenced, Steuer observed that "the biological boundaries within which the Nile exerts its influence from the Delta northwards may be said to lie . . . about the 100 fathom line." Some of my own observations suggest that this is also roughly true with respect to the southeastern shores of the Mediterranean.

In conclusion I should like to quote the results of Riley's investigations on the influence of the Mississippi on the northern part of the Gulf of Mexico.

These investigations were undertaken during the 1937 cruise of the *Atlantis* between March 20 and April 1, and covered examinations of the surface waters with regard to salinity, phosphates, and chlorophyll distribution. The measurements on copper do not bear directly on our problem and are omitted here. The accompanying map (fig. 3) shows the limits at which the influence of the Mississippi was evident in respect to the three factors: salinity, phosphates, and plankton.

To put it briefly: Riley found a marked influence of the Mississippi over a great area; this influence increases the more nearly one approaches the mouth of the river, the highest values being found around its effluent.

The zone of high phosphate content is some 50 km. deep opposite the river and extends westward some 200 km. in a straight line and the same distance eastward to Mobile Bay.

The influence of the Mississippi was also noticeable with regard to phytoplankton, which was richer in this area than in the rest of the Gulf. The area of higher plankton values is greater than that of high phosphate content, as can be seen from the graph, and extends from Mobile Bay in the east probably as far as Galveston in the west, a distance of 850 km. The area of lowered salinity is even greater.

Riley estimates that at the time of his investigations the Gulf received 4700 kilograms of soluble phosphate from the Mississippi per day, a quantity "sufficient to contribute 1 mg. per $m.^3$ daily to 1000 $km.^2$ of surface layer, 80 meters deep." The averages obtained by McHargue and Peters in 1921 are even three times as high.

It is evident from the investigations on the drainage of the Mississippi and the Nile that the fresh-water discharges of the rivers have a great influence on the productivity and the life cycles of the neritic region over large areas. Considering the long span of time that this factor is active, the opinion of Hesse that the oceans owe their different grades of fertility to the different amounts of river water they receive may really be justified.

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METHODS OF FIELD AND LABORATORY PROCEDURE IN PHYTOPLANKTON RESEARCH AT THE SCRIPPS INSTITUTION OF OCEANOGRAPHY OF THE UNIVERSITY OF CALIFORNIA

By W. E. Allen

When I first became associated with the Scripps Institution at La Jolla in 1917 there was no record of species of diatoms living in southern California waters, and there were only the vaguest of surmises concerning total annual production of plankton diatoms, seasonal changes in abundance, geographical differences in occurrence, bathymetrical differences in occurrence, relationships to chemical constituents of sea water, and relationships to physical conditions of sea water including the fundamentally important relationship to movements of water masses, both local and general. Concerning dinoflagellates the situation was much better, thanks to the active interest of Professor C. A. Kofoid, although there was not much reliable information available except in the fields of taxonomy and morphology.

Field work.—Faced with these conditions and strongly impressed by unsatisfactory experience with tow nets as collecting equipment in fresh water, I began immediately to seek for methods by which material could be gathered rapidly, but reliably, at low cost and under widely differing circumstances. By the time that I began permanent residence at the Institution in 1919 I had experimented more or less with all methods of collecting phytoplankton known at that time. As a result I became convinced that filtration of a measured volume of water through No. 25 silk bolting cloth would give the most satisfactory results for plankton diatoms and armored dinoflagellates, the forms already selected as most suitable for long-term researches on marine phytoplankton.

First trials of the measured water method of filtration (as distinguished from centrifuging or settling) were made with a tow net of No. 25 silk (average diameter of openings about .05 millimeter in new material) which was then in use for surface collecting alongside the Institution pier. In these trials a sample was taken by towing over a measured distance calculated to pass 439 liters of water through the meshes. To allow for possible clogging, irregular pull, and other errors of the tow this estimate was reduced to 200 liters for comparison. Immediately following the tow haul 100 liters of water was dipped from a point traversed in the tow and poured through the same net suspended from the pier rail. In 9 pairs of samples the catches by measured water exceeded those by tow in numbers per liter, the preponderance ranging from 12 times to 87 times. Not only was the collecting of measured volumes by filtration easier to control, but the results were far more reliable even in surface work beside the pier. It was seen at once that the adoption of this method would open the way for very great expansion of collecting at the surface level and that its accuracy in operation at subsurface levels might be as important as the accuracy of its results in gathering material from the point of sampling. An officer of the Pacific Coast Steamship Company confirmed part of this expectation almost immediately by obtaining a series of surface catches between San Diego and Seattle, the 3-gallon samples of water to be filtered being dipped from the sea and filtered through a short net while the ship was going at full speed. A little later, members of the scientific staff of the Scripps Institution tested the method for collecting at lower levels, using the Kofoid closing bottle (5 gallons capacity) for getting water from specific levels.

Since 1919 the Institution has accumulated more than 7000 catches of phytoplankton by use of this filtering method, of which about 2000 catches have been obtained at levels below the surface, mostly by aid of the Allen closing bottle (5 liters capacity). Probably not more than one-fifth of that number would have been obtained by any other method. A number of series were obtained from waters of the East Pacific from Peru to the Aleutian Islands and one series even extended as far as Australia. After ten years of use of the method of filtering at the Scripps Institution pier, it was decided to try a settling method in order to capture organisms too small to be retained by No. 25 silk.

Since 1930, daily catches at the pier have been made by dipping a liter of water from the surface alongside (500 milliliters at two different points) and leaving it in a tall glass cylinder after adding a killing fluid. After twenty-four hours the excess fluid is decanted to about 100 milliliters and left in a smaller cylinder from which the excess is again decanted at the next collecting time to leave about 50 milliliters in a small cylinder from which the excess is finally taken by pipette. The remainder is stored in a small vial. Ten years of experience with this method leads to the opinion that it is satisfactory for the diatoms and armored dinoflagellates, while also capturing most of the nannoplankton reasonably well. Because of its convenience and general effectiveness there this method is being continued in use at the Scripps Institution pier. For routine collecting of nannoplankton the settling method appears to be just as good as the centrifuge method preferred by many investigators and it requires much less expense, care, and effort. Both are subject to variable error when handling organisms which are strongly agglutivative, cohesive, or adhesive, but with proper use both may be superior to any kind of filtering method which requires repeated use of the same filtering material because they avoid clogging and spreading of fibers which affect old filtering surfaces. This is especially true when sampling thin populations. However, the use of a conical net for filtering reduces the aging error of mill silk because new filtering surface automatically comes into service as the meshes are clogged in the lower parts of the net. A used net in good condition actually collects plankton diatoms better than a new one when used for filtering, although it would become rapidly worse if used for towing. For practical operation at sea the filtering method is still considered superior to any other for diatoms and armored dinoflagellates.

Microscopic study.—In the course of twenty years, microscopic study of phytoplankton at the Scripps Institution has covered about 26,000 catches. To anyone acquainted with material of this kind it is obvious that careful examination of specimens and rigid identification of component species is not possible with such speed of examination. Still, it is probable that one-fourth of my time and that of my assistants and associates has been devoted to study of specimens in detail. One finds it highly satisfying to deal with material which can be reliably named. Furthermore, it is irritating to be obliged to record forms of doubtful identity. Experiences of more than twenty years involving microscopic examination of hundreds of thousands of specimens has shown conclusively that many species cannot be distinguished unless proper recognition marks are present, that many species grade toward each other to a degree making the establishment of border lines impossible, that almost all species may differ more or less in conformation of individuals according to differences in conditions of development, and that many species must be examined from different angles not possible to obtain in a counting cell. The fact of the matter is that great numbers of individual specimens could never be positively identified even if exhaustive study could be given them and that positive identification of others would require days of careful study, study which would have to be repeated for each individual if full certainty should be sought. This is especially true of the plankton diatoms which sometimes present in a single catch a half-dozen species easily confused and which frequently present in a single catch more than one group of two or three species easily confused. For such reasons the handling of the problem of identifications becomes a feature of method in microscopic study. Except for occasional reviews of the literature and of representative specimens in our mounted collections, I no longer attempt to make exact identification of refractory specimens. If they are not recognizable under the conditions of quantitative study, I record specimens under a catch-all designation, or I apply a species name which expresses a probable relationship at the same time that it serves to separate forms which later study may make identifiable or deserving of special scrutiny.

For routine study under the microscope the volume of the catch is usually reduced to 10 milliliters or 100 milliliters from which 1 milliliter is taken to fill a Sedgwick-Rafter slide, in which it is examined under a magnification of fifty to one hundred diameters. Some correspondence of the last two years has shown that investigators in out of the way places may have trouble in getting that equipment. For that reason it may be worth while to suggest that a temporary S-R slide can be made by building a rectangle on an ordinary microscope slide with paraffine or other wax, or by cementing a rectangle of cardboard of suitable thickness to such a slide with paraffine. The essential thing is to have a waterproof enclosure 1 millimeter deep, 20 millimeters wide, and 50 millimeters long (inside dimensions). For permanent use our University machinists have made for me several frames of brass having these inside dimensions, most of which I have cemented to ordinary glass slides with thin films of paraffine, others with commercial cement. If cover glasses to fit are hard to get in some localities, sheets of mica may be serviceable. At any rate, a little inventiveness may serve to meet the need.

Having mounted a 1-millimeter sample of the catch in a S-R slide I usually count the smallest fraction of the slide that appears likely to give a fair basis for computing the numbers in the catch. The standard fraction for a thin catch is one-tenth of the slide. With the lens combination I am using now this is a little more than one round trip from end to end through the middle of the slide. For heavy catches I often stop with one-twentieth of the slide. Single species found in high abundance are often cut off at less. My view is that it is better to get records of *many* catches which are good approximations than to strive excruciatingly for an accuracy of enumeration and calculation which may be far out of proportion in comparison with the unavoidable errors of sampling in the *few* catches which can be covered under excessive attention to numerical probabilities.

In harmony with this same reasoning I have tried to reduce the time and labor in handling certain series by two different methods. First, at the Institution pier, when populations are running very thin over periods of a week or more, I take a sample from each daily catch for a seven-day period and combine them to obtain an average sample for that time. Enumeration of specimens is then carried through as it might have been for any single catch, and from the numbers recorded the average representation for the seven-day period is calculated. When catches are heavy or when certain days are included in a "plankton pulse" the catch for each day is studied separately in order to obtain details for comparison with records of chemical and physical conditions, but the counts for each seven-day period are averaged. Because our pier records have become so voluminous in the course of twenty years of operation, our standard tabulations include only these averages of weeks (obtained by either procedure), but day-by-day tabulations are also made at times for special purposes. Second, offshore catches of extreme thinness are examined by taking a sample drop from the bottom of the container (without stirring or shaking) and placing it on an ordinary glass slide for the purpose of recording the presence of the few specimens observable. No attempt is made at calculation and the numbers yielded by that catch are simply recorded as negligible. In this connection the term "negligible" is purely quantitative in meaning. The species record covers any qualitative significance. Sometimes thin catches are misjudged and the count is made with the regular S-R equipment. In that case, numbers varying according to circumstances from 100 to 500 per liter are rated as negligible. For some series the saving in microscope and clerical work by these two devices has been more than half. It is safe to say that they have made it possible to bring the routine work on 26,000 catches so nearly up to date with very few laboratory workers. As it is, every important series has been brought to 1939 or into 1939 both in respect to microscopic study and preliminary statistical treatment.

INDICATOR VALUE OF PHYTOPLANKTON

By W. E. Allen

It is generally understood that all kinds (or any kinds) of land-dwelling organisms have more or less value as indicators of habitat relationships, of population trends, and of other environmental or biological conditions, local or regional. It has not been so generally understood, or recognized, that water-dwelling organisms have similar values as indicators. Still, it is well known that in the nearly sixty years since the time of Hensen's attempts to use plankton populations for estimating fertility, or productivity, of the sea, increasing numbers of investigators have undertaken to use marine life in numerous ways for "indicator" purposes.

At the Scripps Institution of Oceanography, researches on marine phytoplankton were initiated in 1917 for the primary purpose of assembling data to indicate conditions, and changes of conditions, of fertility of California seas. At that time it was assumed that marine life resembled land life in being dependent on the abundance and activities of photosynthetic organisms (ordinarily roughly grouped together as "green plants"). It was assumed also that the microscopic "green plants" afloat in the sea contributed most to support of marine populations of animals, among which commercial fishes were most conspicuous. Preliminary studies in southern California, as well as results of North Sea and other investigations, led to the additional assumption that marine diatoms and dinoflagellates were the groups most favorable for observation while being at the same time fairly representative in respect to photosynthetic activities.

Because of war-time interest in marine sources of human food, the first studies of phytoplankton at the Scripps Institution were designed particularly for getting information indicative of abundance of "ocean pasturage" in that region. While the work of the summers of 1917 and 1918 may seem absurdly inadequate and inconsequential in the light of our knowledge of today, it did show that phytoplankton was not distributed uniformly through the water, that its abundance was not constant in any locality at any level, and that proportional representation of species was continually changing in all populations. In other words, it became evident that "indicator values" of plankton diatoms or any other organisms were obscured by the intricacy of relationships, and the kaleidoscopic changes of relationships, to such a degree that they could not be applied immediately and directly to the problems of sustenance of commercial fishes.

However, the original assumption that changes in abundances of diatoms and dinoflagellates were closely related to changes in general productivity of the sea was not abandoned. Instead of stressing the idea of using phytoplankton populations as indicators of presence or absence of marketable fish within a given area, it was decided to use them as indicators of regional trends of fertility, or productivity, over periods of years, or even decades. Consequent to this decision the Institution established a series of daily collections of phytoplankton at its pier in 1919, supplemented by such series in other localities a little later. These series have shown a high value of phytoplankton populations for use as indicators of relative fertility of different localities and regions in different seasons and years. For example, La Jolla Bay showed more production than Point Hueneme (near Oxnard, California, more than 100 miles distant northerly) for the first three years (less thereafter), while showing a fairly close resemblance to Oceanside (25 miles away) through five years. Over a period of five years, daily catches at the Farallone Islands (outside of San

Francisco Bay) showed very thin populations only, indicating low fertility of the sea near the islands. Another daily series at Scotch Cap in the Aleutian Islands showed intermediate production of diatoms and dinoflagellates. Thus, by use of phytoplankton populations as indicators, we get the idea of extreme differences between regions in respect to productivity.

For the benefit of those not familiar with the vagaries of distribution of oceanic populations of all kinds, perhaps it should be noted that heavy production of "pasturage" at a particular time or place, or over a considerable period, does not mean, necessarily, that commercial fishes or other animal populations must be abundant also there and then. For one thing, great density of phytoplankton is well known to be distasteful or detrimental to animal populations. Also, plant production may be heavy at a time when few animals are in a condition to use it. Furthermore, the phytoplankton may be consumed mainly in a locality less favorable for its growth after drifting away from a locality highly favorable for its production. That is to say, locality records may indicate good fertility in respect to one type of organisms and not for others. For such reasons it appears certain that while marine diatoms and dinoflagellates may reach abundances indicating good fertility of the sea in a particular locality, it cannot be assumed that they indicate reliably the degree of productivity of animal populations. That value may appear in the future, but it is not available from present knowledge.

The indicator values of large abundances of phytoplankton in respect to movements of water masses are much more satisfactory, as exhibited by different series of collections obtained by the Scripps Institution in a period of twenty-two years. Even the less satisfactory series of 1917 and 1918 showed larger catches of phytoplankton to be related to "upwelling." Doubtless "upwelling" may occur without being accompanied by increase in abundance of plants, but in certain localities large abundance of "ocean pasturage" definitely does indicate "upwelling." Later investigations by the Scripps Institution, especially in the cruises of 1938 off the coast of southern California, have shown also that good or large abundances of marine diatoms are good indicators of the paths of flow of major currents moving more or less nearly parallel with the coast and of certain eddies or circuits developed by them.

To agriculturists it is well known that land plants of many kinds are good indicators of soil conditions, not only in respect to productiveness, but also in respect to chemical composition or physical constitution. In some instances abundance is the main feature of indicator usefulness. In other instances the characteristics of form and development of individual plants are more important. Acid soils, alkali soils, wet soils, dry soils, and various types and combinations of types may support more or less vegetation tolerant of their peculiarities. An experienced man driving rapidly along a highway can usually make a close guess at the characters of the soils within his view, merely by use of plant indicators.

For at least one very good reason the floating plants of the sea have never reached so high a degree of indicator value: their microscopic size has prevented observations and comparisons requisite for dependable understanding of relationships. In addition, it should be noted that constituents of the sea-water substratum are not so stable in respect to either kinds or quantities as are the constituents of most land substrata. Nevertheless, it appears that there is opportunity for considerable usefulness of phytoplankton indicators of conditions of the sea-water substratum. Doubtless this is easiest to see in those species of diatoms which are known to thrive best on the high seas, or in coastal waters, or in estuaries, or in brackish waters, or in high latitudes, or in low latitudes. But it may be equally important if certain species show marked changes in abundance or in conformation according to changes in salinity, temperature, or abundance of particular chemical constituents. As our knowledge of the composition of sea-water and its changes or variations becomes more accurate, such indicator values of plankton diatoms and other microscopic plants should increase greatly. Indeed, for certain investigations they may reach prime importance by attracting attention to the fact that a given sample of "sea water" has peculiar properties or that it contains some substance which affects the plants although it may go unnoticed in the routine of direct chemical examinations. Of more practical application is the use of a series of phytoplankton samples running parallel with a series of chemical samples to verify or substantiate the chemical observations. In the Institution cruises of 1938 it happened at one time that Station 9 showed some chemical conditions different from those expected and that some doubt arose concerning the validity of the chemical work for that station. Comparison with the diatom records for that station revealed differences of similar magnitude in numbers of diatoms and authenticated the chemical work. This experience not only presents new convincing evidence that phytoplankton has indicator values worth developing and exploiting, but it also shows the high importance of close coöperation and coördination between all kinds of oceanic investigation.

AGE, GROWTH, AND SEASONAL TIME OF MIGRATION OF THE PACIFIC SALMON AS AN INDICATION OF ENVIRONMENTAL CONDITIONS IN THE SEA

By F. A. Davidson

THE PINK SALMON differ from the other species of Pacific salmon in that they have a complete two-year life cycle. The eggs are spawned in the fall and hatch out the following spring. The fry after absorption of the yolk sack migrate directly to the sea, where they feed until the summer of their second year of life. During their 16 to 18 months' sojourn in the sea they mature, and afterward they return to the streams to spawn and die. The salmon begin to migrate into the streams in July and continue through August. By the middle of September most of the salmon are in the streams and spawning is taking place.

Owing to this consistent two-year life cycle of the pink salmon, they must of necessity begin their spawning migration to the streams at the close of their second year of life regardless of the growth they have attained while in the sea. All evidence thus far available indicates that in years when environmental conditions in the ocean are favorable they have a better opportunity to attain their full growth before migrating to the streams. In such years the fish are relatively large in size and the majority migrate to the streams early in the season. In years, however, when environmental conditions are not inducive to growth, they tend to remain longer in the sea in an attempt to attain their full growth. In such years they often remain in the sea so long that the onset of sexual development forces them to begin their spawning migration regardless of their state of physical maturity. Under these conditions the majority migrate to the streams late in the season and the individuals are usually relatively small in size.

Owing to the variable life cycle of the other species of salmon, they return at different ages, ranging from two to eight years. The sockeye or red salmon may spend from one to four years in fresh water and from one to four years in the sea. The seasonal time of migration of this species in Alaskan waters fluctuates from year to year, but not to so great a degree as does the time of appearance of the pink salmon. Furthermore, the size of the individuals in the various age groups remains more or less constant. However, the age at which the salmon return to spawn at times fluctuates markedly. This may be attributed to the choice, so to speak, that the sockeye have of remaining in the sea an additional year or two if environmental conditions are not favorable to their growth. Therefore they indicate the biotic conditions in the sea, not by their size and time of migration as do the pinks, but by the age at which they return to the streams. This may be illustrated by the age of red salmon that returned to the stream at Chignik, Alaska, in 1932 and 1933. In 1932, instead of the usual ratio of 4- and 5-year-old salmon in the run at Chignik, there was a marked deficiency in the 4-year-old age classes. For this reason the total run of salmon was not so large as expected. In 1933, the 5-year age class was far above normal in abundance and the run was double the expectation. In other words, the fish that would normally have returned as 4-year-olds in 1932 remained in the sea and returned as 5-year-olds in 1933. The average age at which the sockeye return to other streams in Alaska has likewise been found to vary quite widely at times and may be attributed to the variable growth rate of the salmon in the sea and the subsequent age at which they migrate to the streams.

These phenomena are continually occurring in the life histories of the Alaska salmon and their study opens channels for future investigation of both theoretical and practical value.

COMPOSITION OF PLANKTON AND UNITS FOR REPORTING POPULATIONS AND PRODUCTION

By RICHARD H. FLEMING

THE FOLLOWING discussion deals with two general problems: first, the ratios between certain essential constituents of marine organisms; and second, rational units for reporting quantities of plankton and the numerical relationships between these units. High accuracy cannot be claimed for either the ratios or the numerical relationships between various types of plankton units. The available data show a considerable range and, furthermore, the quantitative relationships will depend somewhat on the method by which they are computed. Consequently, although the method of treatment is valid, the numerical values must be considered as tentative and subject to some revision when additional data are available.

In 1934, Redfield pointed out that the proportions of carbon, nitrogen, and phosphorus in plankton organisms were rather constant and that these ratios corresponded closely to those for sea water. Since then, Seiwell (1935), Cooper (1935, 1937–38, and 1938*a*) and von Brand (1935) have supplied additional information on these ratios which differ somewhat from those given by Redfield. Furthermore, Cooper (1938*b*) has pointed out that Redfield's ratios for sea water must be modified because of the salt error in the determination of phosphate phosphorus which was not taken into account in the earlier estimations. From the available data, which included certain material given by Vinogradov, analyses were selected for the calculation of the ratios of C:N:P in both zoöplankton and phytoplankton. In making this selection certain determinations which showed pronounced departures from the general average were omitted. Some adjustments were necessary in order to determine the best average ratios for all three elements, as in most cases only a single ratio, that is, either C:N, N:P, or C:P was determined. In this discussion "carbon" will be taken to mean organic carbon exclusive of carbon which may be present in calcareous structures. The final ratios obtained in this way are shown in table 1.

TABLE 1

RATIOS OF C:N:P IN PLANKTON AND SEA WATER

Authority	Material	(By weight)				(By atoms)		
		C	N	P	C:N	C	N	P
Redfield (1934)	Plankton	53.2	8.2	1	6.5	...	..	..
Redfield (1934)	Sea water	54.1	9.0	1	...	140	20	1
Cooper (1938*b*)	Sea water	....	6.8	1	...	...	15	1
New estimates	Phytoplankton	42	7	1	...	...	..	..
	Zoöplankton	40	7.4	1	...	...	..	..
	Average	41	7.2	1	...	106	16	1

As the difference between the average ratios for zoöplankton and phytoplankton were so small, it was decided that they were not significant because of the wide spread of individual determinations, and consequently a combined average set of ratios will be used in the following discussion. It may be seen from table 1 that the new ratio of N:P in plankton corresponds very closely to the ratio for sea water proposed by Cooper (1938*b*).

Redfield laid particular emphasis upon the fact that the ratios of C:N:P in plankton were virtually the same as the values he obtained for sea water. He offered two possible explanations for this agreement, which must still be considered, as the new averages for plankton are very close to those for sea water. Redfield suggests either that the ratios in sea water are ideally suited for the organisms living in it, or that the character of the population, of which different species may require these elements in different proportions, is so controlled by the amounts available that all are ultimately reduced to threshold values. A third possibility, not offered by Redfield, which must be considered is that with respect to those elements which are present in very low concentrations the phytoplankton utilize all the material they can obtain. If we assume that there is no difference in the absorption of the different ions, they will then be removed from the water in the same proportion as the ratios of their concentrations. If this is the fact, the proportions in the phytoplankton, at least of nitrogen and phosphorus, would correspond to the ratios in the water. If this is true, the ratio of N:P in phytoplankton would vary somewhat if there are any variations in the relative amounts present in the water. Evidence that the ratio in diatoms may depend upon the relative quantities in solution has been found by Sargent (1939). Although the ratios in phytoplankton may be determined by the supply, the composition of zoöplankton is not necessarily determined by such a factor. Consequently there may be significant differences between the ratios in animal and plant plankton, although these do not show up in the averages given in table 1. Such possible differences should be kept in mind.

Accurate knowledge concerning the ratios of various elements in plankton is important in many connections. If the ratios between certain elements, such as those for C:N:P given in table 1, are constant, they can be used in many ways. If we are dealing with a given volume of water in which there is no differential gain or loss of materials to the surroundings, the determination of the time variations in the concentration of, say, phosphate, can be used as a measure of the corresponding changes in the carbon and nitrogen in the water. Furthermore, such ratios would be very helpful in studies of the relative rates of regeneration of these elements. If we now consider the quantity of plankton, the determination of any one of these elements in the catch will be a measure of the others. When expressing quantities of plankton, however, the statement that a plankton catch contains a certain amount of carbon does not convey any real picture of the volume or quantity of organisms present. Therefore it is desirable to know the relationships which exist between quantities of carbon, nitrogen, and phosphorus and certain units which have been used in plankton research. Furthermore, unless such relationships are known, conventional methods of reporting plankton cannot be related quantitatively either to their contents of certain chemical elements or to changes in the concentration of these elements in the water. Finally, calculations of the total production in a given interval, based on the utilization of essential elements, such as those made by Cooper (1933 and 1938*c*), require knowledge of the numerical relationships between the variable elements and the corresponding amounts of plankton. Estimates of the total production in a given interval based on the utilization of any essential element assumes that regeneration is negligible. If it is not, a correction must be applied for this factor. The change in population of a given water mass need not correspond to the production in the same time interval, because it is possible that a considerable quantity of the element, used as the basis of the calculation, has been excreted or released in a form not detected in the analysis of the water. Furthermore, plankton produced in a given volume of water may be removed by pelagic organisms which have consumed this material and then migrated elsewhere.

Plankton populations are usually expressed by enumeration of the numbers of different types of organisms obtained from a certain volume of water. Because of the tremendous range in size, shape, and composition of the organisms, such enumeration gives no measure of the quantity of carbon, nitrogen, or phosphorus, unless the size and composition of the individual types of organisms are known and taken into account. One approach to a quantitative expression of the amount of plankton which may show some relationship to its content of, say, nitrogen is to determine the volume or weight of the plankton catch. Various methods for determining the volume of plankton have been suggested, such as allowing the material to settle in graduated cylinders or by centrifuging. Such methods are bound to yield variable results, depending not only upon the technique followed, but also upon the nature of the individual plankton samples. Another method which should yield a fairly good relationship to the essential elements is that of determining the dry weight of the plankton samples. Even here there will be a wide range because of the differences in the relative proportions of inorganic skeletal material in different types of organisms. When dealing more specifically with phytoplankton, the problem is not quite so complicated. Harvey (1934) has shown that the phytoplankton population can be expressed in terms of plant-pigment units, and Harvey, Cooper, Lebour, and Russell (1935) have suggested the use of diatoms of "average cell contents" to express the quantity of phytoplankton. Therefore, with respect to phytoplankton it is possible to use quantitative units which will bear a much closer relationship to their content of essential elements. In the rest of this discussion, various quantitative relationships are presented which relate the different units for reporting plankton and their content of carbon, nitrogen, and phosphorus.

Starting with the relationship that the C :N :P ratios in marine plankton are 41 :7.2 :1, it is possible to determine quantitative relationships between these elements and various units for reporting quantities of plankton. Harvey, Cooper, Lebour, and Russell (1935) determined the phosphorus content of phytoplankton samples the content of which in plant-pigment units had been measured and obtained an average of 1 mg. of phosphorus for every 12,500 plant-pigment units. Furthermore, they found that 1 mg. of phosphorus was equivalent to 50×10^6 diatoms of "average cell contents." One diatom of average cell content is shown to be equal to 3 cells of *Rhizosolenia alata*, 3½ cells of *Rhizosolenia shrubsolei*, or 20 cells of *Skeletonema costatum*. Sargent (1939) has found in culture experiments that the minimum phosphorus content of *Nitzschia closterium* is 1 mg. in $14{,}000 \times 10^6$ cells. From these relationships it is possible to calculate the numerical equivalents shown in table 2.

Atkins (1923) introduced the unit "wet plankton" when estimating the production of plankton in the English Channel from the utilization of phosphate phosphorus. The quantitative relationship used by him was that 1 mg. of phosphorus was equivalent to 1520 mg. of "wet plankton." Unfortunately, this relationship was not directly determined for plankton, but was based on analyses of seaweed, and hence calculations actually represent the equivalent quantity of wet seaweed. Cooper (1933 and 1938*c*) has computed the production in terms of "wet plankton" from the consumption of phosphorus, carbon, and nitrogen and the release of oxygen. Gilson (1937) has recomputed Seiwell's estimate (1935) based on oxygen consumption below the photosynthetic zone in these terms. The same method has been used by Sverdrup and Fleming (in press).

TABLE 2

PLANKTON EQUIVALENTS

Ratios, C:N:P = 41:7.2:1 (by weight)

	Carbon 1 mg.	Nitrogen 1 mg.	Phosphorous 1 mg.	Plant pigment 1 unit	Diatoms avg. conts. 1 cell	"Wet plankton" 1 mg.	Dry plankton 1 mg.	Settling volume 1 ml.	Displacement volume 1 ml.	Oxygen equivalent 1 ml.
Carbon (mg.)	1	5.7	41	3.3×10^{-3}	0.8×10^{-6}	0.027	0.44	1.4	5.6	0.536
Nitrogen (mg.)	0.18	1	7.2	0.58×10^{-3}	0.14×10^{-6}	0.0047	0.0765	0.24	1.0	0.097
Phosphorus (mg.)	0.024	0.14	1	0.08×10^{-3}	0.02×10^{-6}	0.00066	0.011	0.034	0.14	0.013
Plant pigment (units)	305	1,740	12,500	1	250×10^{-6}	8.25	133	412	1690	163
Diatoms, avg. conts. (cells)	1.2×10^{6}	7.0×10^{6}	50×10^{6}	4×10^{3}	1	0.033	0.5×10^{6}	1.5×10^{6}	6×10^{6}	0.6×10^{6}
R. alata (cells)	3.7×10^{6}	21×10^{6}	150×10^{6}	12×10^{3}	3.0	0.10×10^{6}	1.6×10^{6}	5.0×10^{6}	20×10^{6}	2.0×10^{6}
R. shrubsolei (cells)	4.3×10^{6}	24×10^{6}	175×10^{6}	14×10^{3}	3.5	0.12×10^{6}	1.8×10^{6}	5.6×10^{6}	23×10^{6}	2.3×10^{6}
S. costatum (cells)	$24.\times10^{6}$	139×10^{6}	$1{,}000\times10^{6}$	80×10^{3}	20	0.66×10^{6}	11×10^{6}	34×10^{6}	140×10^{6}	13×10^{6}
N. closterium (cells)	341×10^{6}	$1{,}950\times10^{6}$	$14{,}000\times10^{6}$	$1{,}120\times10^{3}$	280	9.2×10^{6}	149×10^{6}	462×10^{6}	$1{,}890\times10^{6}$	183×10^{6}
"Wet plankton" (mg.)	37	211	1520	122×10^{-3}	30×10^{-6}	1	16	50	203	20
Dry plankton (mg.)	2.3	13.1	94	7.5×10^{-3}	1.9×10^{-6}	0.06	1	3.1	12.7	1.2
Settling volume (ml.)	0.7	4.2	30.2	2.4×10^{-3}	0.6×10^{-6}	0.02	0.32	1	4.1	0.4
Displacement volume (ml.)	0.18	1.0	7.4	0.59×10^{-3}	0.15×10^{-6}	0.005	0.08	0.25	1	0.1
Oxygen equivalent (ml.)	1.9	10.6	76.	6.1×10^{-3}	1.5×10^{-6}	0.05	0.8	2.5	10.2	1

Cooper's value for wet plankton based on phosphorus consumption corresponds with that given in table 2, but the relationship to carbon, nitrogen, and oxygen equivalent will differ because the ratios of C:N:P used by Cooper are 91:7.6:1. That is, Cooper's "wet plankton" contains more than twice as much carbon as that given in table 2 and hence the oxygen equivalent will differ as well.

The relationship for dry plankton is based upon the observations of Moberg (1925), who determined the nitrogen content of 49 samples of dry, salt-free, mixed plankton. The average nitrogen content was found to be 1 in 13.1 parts of dry plankton.

The relationship for the settling volume is also based on Moberg's observations. The mixed net plankton was placed in graduated cylinders and the volume of settled material read at the end of 48 hours. These samples were later washed and dried and their dry weight determined. From 56 such determinations he found that 1 mg. of dry plankton occupied 3.1 ml. (probable error ± 1.0) when allowed to settle for 48 hours.

The displacement volume relationship is based on observations by Dr. Martin W. Johnson (unpublished material), who examined 115 net-plankton samples and determined the settling volume in approximately the same manner as Moberg. The plankton was then concentrated on a filter and placed in a graduate containing some water. The increase in volume was taken as the displacement volume for that sample. The relationship between settling volume and displacement volume found from the 115 samples was that 1 ml. by displacement was equivalent to 4.1–0.7 ml. by settling. The displacement volume determined in this way is not the actual volume of plankton, as a considerable quantity of water must be retained by the plankton.

The oxygen equivalent has been calculated on the assumption that the oxidation of 1 atom of carbon requires 2 atoms of oxygen and that the same amount is released during photosynthesis. Gilson (1937) has pointed out that such a relationship cannot hold true as the nitrogen in the organisms is also oxidized. Gilson suggests that the oxygen equivalent should be 20 per cent greater.

From the sources described above the numerical equivalents between these various units have been computed. These are given in table 2.

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QUANTITATIVE STUDIES OF THE NERITIC LITTORAL MICROPLANKTON OF JAPAN COLLECTED AT SIXTEEN STATIONS RANGING FROM SAGHALIEN TO FORMOSA, 1931–1933

By Seiji Kokubo

Introduction

The subject of the present investigation was first suggested by Professor S. Hatai at a meeting of the biological and agricultural sections of the National Research Council of Japan held on February 1, 1930, with the late Professor S. Goto as chairman. A further meeting was held on April 15, the following experts being present: Mr. H. Aikawa (Imp. Fish Inst.), Assistant Professor K. Akatuka (Kyôto Imp. Univ.), Professor S. Goto (Chairman, Tôkyô Imp. Univ.), Professor S. Hatai (Tôhoku Imp. Univ.), Assistant Professor K. Ito (Tôkyô Imp. Univ.), Assistant Professor S. Kokubo (Tôhoku Imp. Univ.), Mr. S. Kuragami (Fish. Exp. Sta. Hokkaidô), Mr. Marukawa (Imp. Fish. Inst.), Professor H. Osima (Kyûsyû Imp. Univ.), Mr. Nisida (Fish. Exp. St. Tyôsen), Professor N. Yatu (Tôkyô Imp. Univ.). It was then decided that a collection of plankton should be made bimonthly by Kokubo's settling method at sixteen representative stations in Japan, the stations to be situated approximately one mile from the coast, and that, as far as possible, oceanographic conditions be studied simultaneously.

Collection was subsequently begun at selected stations, a list of which will be given later. A specimen from each station was sent to the Asamusi Marine Biological Station for examination by the investigator, and the results were published in the *Plankton Journal* (issued in Japanese), fifteen numbers of which have appeared to date. The total number of specimens secured during the period 1931–1933 was 450. Of these, those collected at Tateyama and Daityô were examined by H. Marukawa and those collected at Rakuma by the late F. Fujita.

The writer is greatly indebted to the National Research Council of Japan, by which a portion of the expenses incurred during the investigation has been defrayed. His thanks are also due to S. Hatai for advice during the course of the work and to A. Suzuki for his assistance with practical work.

Method of Investigation

Collection of plankton.—The method of collection was the same as that previously employed (Kokubo, 1932), that is, at any given station 10 liters of surface water was collected and 100 cc. of formaline saturated with picric acid was added, the whole being thoroughly shaken. After 24 hours the supernatant water was decanted, leaving about 1 liter of water and sediment undisturbed in the bottle. The water together with the sediment was then transferred to a settling cylinder (capacity 1 liter) with tapered bottom and allowed to settle for more than 24 hours. The superfluous water was drained off through a stopcock near the bottom. The plankton with about 15 cc. of water was then transferred to a small preserving bottle. The material obtained was used for counting.

Counting of plankton.—For counting plankton a slide glass, 60 by 40 mm. in dimension with the surface graduated at every ½ mm., was used. The cover glass used was 28 by 28 mm., making it possible for a 0.1-cc. sample to be covered conveniently. The specimen thus prepared was placed on the ordinary mechanical stage of the microscope and counted by moving the slide glass

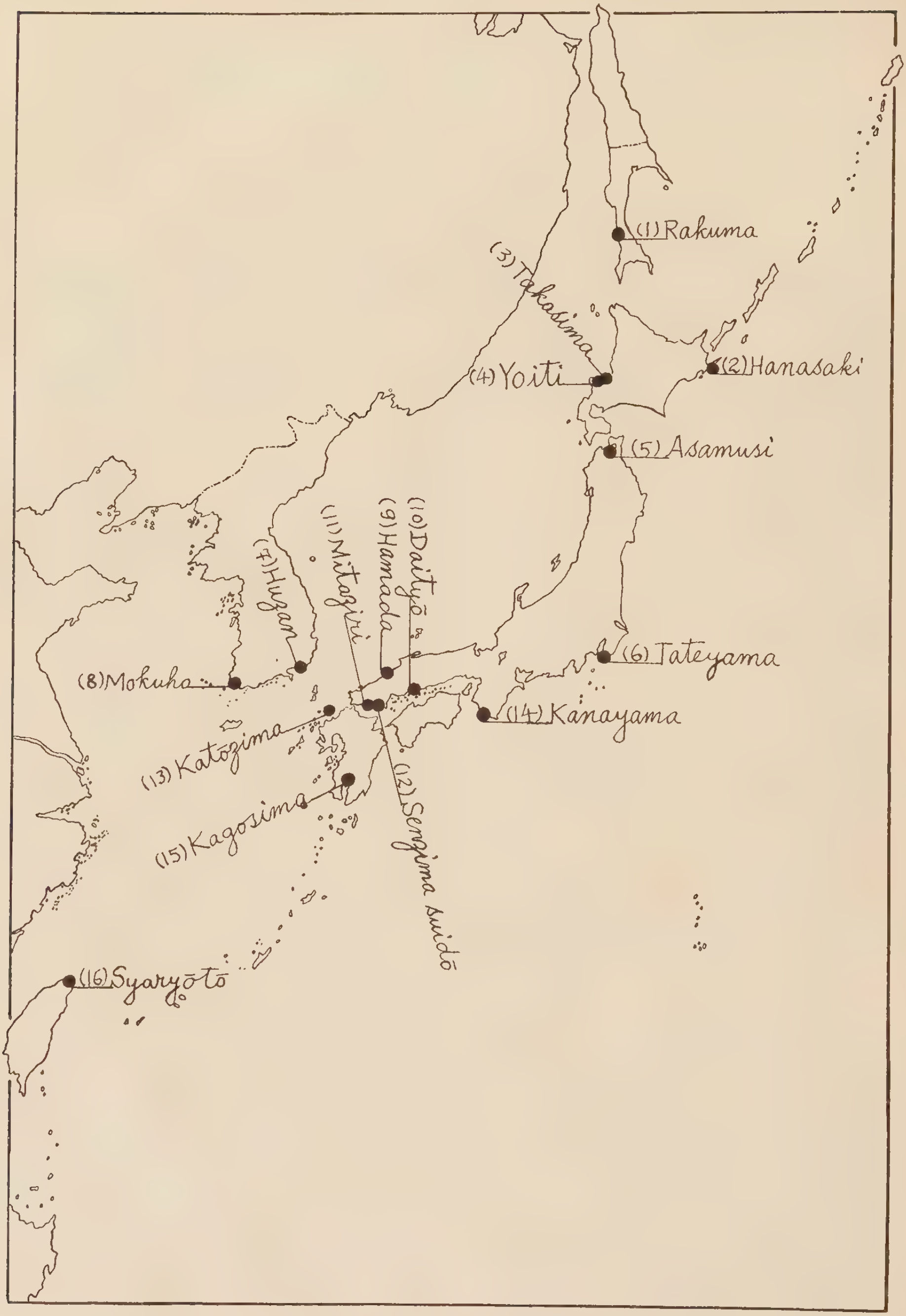
(1) Rakuma
(2) Hanasaki
(3) Takasima
(4) Yoiti
(5) Asamusi
(6) Tateyama
(7) Huzan
(8) Mokuho
(9) Hamada
(10) Daityō
(11) Mitaziri
(12) Sengima suidō
(13) Katōzima
(14) Kanayama
(15) Kagosima
(16) Syaryōtō

Fig. 1. Distribution of collecting stations.

lengthwise. When counting settled plankton, Utermohl's (1931) reversed microscope as applied by Nielsen (1933) to marine plankton may be used with advantage. In the present investigation, however, no such special equipment was used.

Hydrographic observations.—As the present observation was concerned with littoral plankton, it was necessary to observe neritic oceanographic conditions which may vary markedly with season and locality. For this purpose, water temperature, specific gravity, pH, transparency, color of water, and wind and weather, were observed at each station. The results of these observations threw much light upon the conditions affecting plankton.

Collecting stations.—The collecting stations ranged geographically from Saghalien to Formosa, that is, from subarctic to tropical waters, including the temperate zone. Originally, ideally situated stations in various parts of Japan were chosen, but afterward some changes were made because of practical difficulties. The stations where regular collections were made were:

1. Rakuma (west coast of Saghalien)
2. Hanasaki (Pacific coast of Hokkaidô)
3. Takasima (west coast of Hokkaidô)
4. Yoiti (west coast of Hokkaidô)
5. Asamusi (Mutu Bay, Aomori prefecture)
6. Tateyama (Pacific coast of Tiba prefecture)
7. Huzan (southeast coast of Korea)
8. Mokuho (southwest coast of Korea)
9. Hamada (Japan Sea coast of Simane prefecture)
10. Daityô (Seto Inland Sea, Hirosima prefecture)
11. Mitaziri (ditto)
12. Senzima-suido (ditto)
13. Katōzima (Japan Sea coast of Saga prefecture)
14. Kanayama (Pacific coast of Wakayama prefecture)
15. Kagosima (Kagosima Bay, Kagosima prefecture)
16. Syaryôtô (northeast coast of Formosa)

At most of the above-named stations the depth ranged from 20 to 30 meters, but at Hamada it was as much as 50 meters and at the Inland Sea stations such as Senzima-suido it was only 2 meters.

Results of Investigation

OCEANOGRAPHIC CONDITIONS: WATER TEMPERATURE

Water temperature.—The temperature of the water off the coast of Japan has been reported by Seki (1930) and Kurasige (1935). According to them, the monthly average temperature in the south, for example at Formosa and Okinawa, ranges from a minimum of 15° C. to a maximum of 28° C. with an annual average of 23° C. or more, the annual fluctuation being less than 10° C. North of Hokkaidô and in Hokkaidô itself the minimum monthly average is around — 1.0° C., the maximum average being 20° C. or under and the annual fluctuation sometimes exceeding 20° C.

During the present investigation the coldest station proved to be Hanasaki (Hokkaidô), with an annual average of 6.4° C. in 1932 and 7.0° C. in 1933, this being colder than Rakuma in Saghalien. This shows that Hanasaki is affected by the Oyasiwo cold current, probably being the coldest region in Hokkaidô. Takasima and Yoiti differ but little in latitude from Hanasaki, but the temperature at these two places is much higher than at Hanasaki. This is doubtless due to the Tuma current, which passes west of Hokkaidô. Huzan and Mokuho in Korea are definitely warmer than Asamusi, but, in spite of their latitude, far colder than Hamada and Katōzima. This is probably due to the cold current which flows down from the north along the Korean coast, as may be surmised from Nisida's (1926) report.

TABLE 1
WATER TEMPERATURES

Station	Year					
	1931		1932		1933	
	Temperature (C.)		Temperature (C.)		Temperature (C.)	
	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum
1. Rakuma	....	....	6°0 (June)	16°2 (Aug.)	2°8 (Apr.)	−0°4 (Jan.)
2. Hanasaki	14°6 (Sept.)	5°6 (Dec.)	12°2 (Oct.)	−0°7 (Jan.)	13°0 (Aug.)	−1°5 (Feb.)
3. Takasima	10°0 (June)	6°5 (May)	....	....	....	....
4. Yoiti	....	....	18°6 (Oct.)	9°4 (May)	12°5 (Nov.)	22°8 (July)
5. Asamusi	5°6 (Mar.)	7°0 (Jan.)	12°3 (May)	8°5 (Apr.)	11°7 (May)	7°3 (Apr.)
7. Huzan	22°7 (Sept.)	13°5 (Dec.)	21°0 (Sept.)	19°4 (July)	14°8 (May)	10°3 (Feb.)
8. Mokuho	25°7 (Aug.)	8°3 (Dec.)	6°5 (Feb.)	6°2 (Mar.)	16°6 (May)	11°3 (Apr.)
9. Hamada	22°9 (Oct.)	13°2 (Mar.)	15°3 (Feb.)	17°7 (Dec.)	20°0 (Nov.)	12°8 (Feb.)
13. Katōzima	12°6 (Mar.)	....	13°6 (Feb.)	15°1 (Dec.)	20°0 (Nov.)	18°1 (Dec.)
14. Kanayama	24°2 (June)	24°2 (June)	....	....	....	....
16. Syaryôtô	24°0 (Feb.)	24°8 (Mar.)	....	....	....	....

To turn to the Pacific coast, Kanayama, with an annual average of 21.5° C. (1931), is warmer than any of the other stations. Kagosima tends to be colder than Kanayama, probably because it is in an inland bay uninfluenced by warm currents. Syaryôtô (Formosa), the southernmost and hence the warmest of all the stations investigated, shows an annual average of 25.13° C. (1931).

Temperature and diatom vegetation.—Biological phenomena such as plankton diatom vegetation may be regarded as a function of many variables, such as temperature, light, salinity, nutriment, and movement of water. Under experimental conditions some of these variables can be kept unchanged in order to observe the effect of a certain factor, but under natural conditions they vary at random. It is therefore extremely difficult to argue the relationship of any single factor such as, for example, temperature, to the diatom vegetation. In the present study, therefore, a mere comparison of the water temperature and maximum diatom vegetation is given in table form (table 1) with brief comments.

It can be seen from table 1 that:

1. The temperature at which a maximum of diatom vegetation is found varies with the locality. If there exists any very close relationship between temperature and vegetation, maximum vegetation must occur at a definite temperature. This suggests the existence of influential factors other than temperature alone.
2. The water temperature at which the diatoms multiply varies year by year at any given station, as may be seen clearly from table 1 with respect to Asamusi and Mokuho. This may also suggest the influence of other factors.
3. Water temperature tends to be higher during the maximum than during the minimum season. It is generally believed that diatoms avoid the warmest season when vegetating, but table 1 shows that they also avoid the coldest season.

With regard to the relationship between temperature and vegetation, it is generally supposed that the vernal increase of diatoms synchronizes with the vernal warming of the water, as apparently is often true. Bigelow (1926) observed, however, that in the waters between Cape Ann and the Isles of Shoals, diatoms commenced to multiply actively while the temperature was at its winter minimum. Kokubo (1932) also found that in Aomori Bay (1929) the vernal increase of diatoms began before the vernal warming of the water. These facts seem to suggest that, in certain circumstances, vegetation is governed by factors other than temperature. Experimental studies carried out by Allen and Nelson (1910) show that a temperature above 17° C. is favorable for diatom vegetation, whereas any temperature below this functions adversely. Under natural conditions, however, maximum diatom vegetation is often found above 17° C. The temperature 17° C. cannot therefore be taken as having any absolute significance.

OCEANOGRAPHIC CONDITIONS: SPECIFIC GRAVITY OF SEA WATER

In the neritic region the specific gravity of sea water not only shows a wider range of variation but also a much lower value as compared with the open sea. This variation and low value are caused by changes due to land drainage, with the result that the specific gravity varies with locality and season. Hence the specific gravity of neritic water has been thought to have some marked bearing upon the ecology of littoral regions.

Specific gravity of sea water.—Generally speaking, the specific gravity of Japanese coastal waters is high (around 26.00) in the south and low (around 25.00) in the north, being relatively constant in the offshore regions. In coastal waters the specific gravity often depends upon local conditions such as river drainage or a temporary snow-water freshet and is far below that of the offshore waters.

The results of the present investigation show that the specific gravity of sea water is highest at Syaryôtô (Formosa) (25.67 mean, 1931) and lowest at Hanasaki (Hokkaidô) (23.94 mean, 1931–1933). Of the sixteen stations, high values over 25.00 were found at Syaryôtô (25.67), Katōzima (25.27), and Rakuma (25.01). Moderate values of 25.00–24.00 were found at Huzan and Takasima, and low values under 24.00 at Asamusi (23.97), Yoiti (23.97), and Hanasaki (23.94). Of these values, that of Rakuma (25.01) is relatively high for a northern station. But it can be accounted for by the Tusima current, which exerts its maximum influence owing to the lack of rivers in this vicinity.

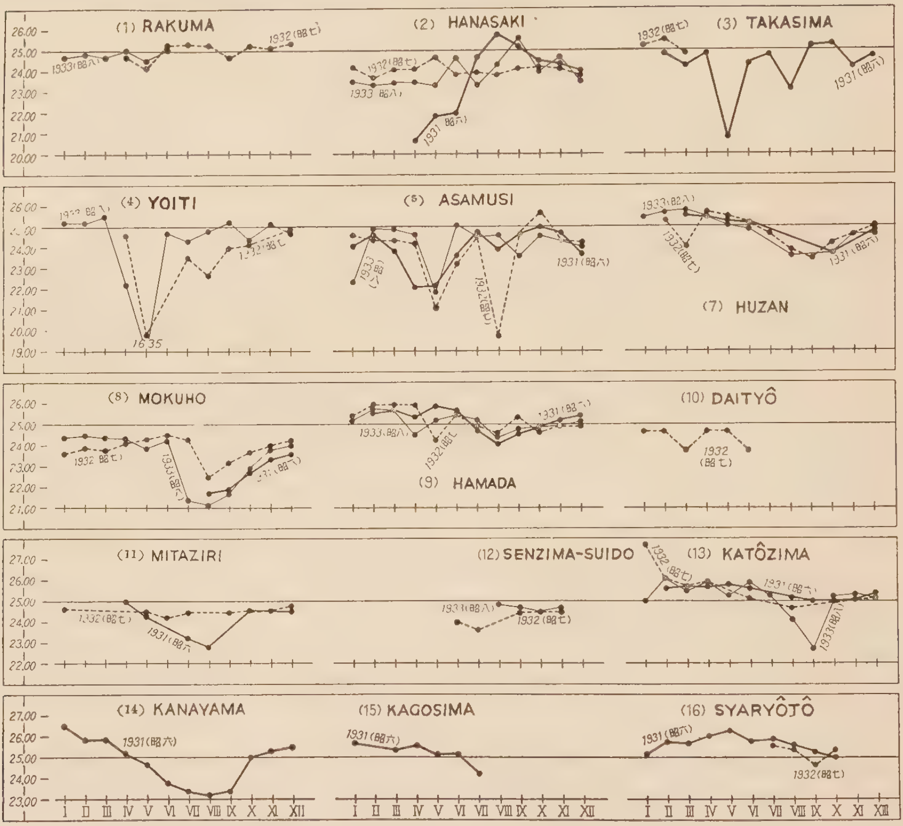

Fig. 2. Seasonal changes in specific gravity of sea water at fifteen stations.

Of the changes in specific gravity at any definite station, we note a seasonal change, that is, the change which occurs more or less regularly from year to year (fig. 2). Examination of the seasonal change at fifteen stations shows two modes of change. In the first place, there are stations where the minimum value is found in autumn (Aug., Sept.), as at the southern stations of Huzan, Mokuho, Hamada, and Syaryôtô. In the second place, there are stations where the minimum value is found in spring (Apr., May), as at the northern stations of Asamusi, Yoiti, Takasima, and Rakuma.

In general, changes in the specific gravity of neritic waters are due to fluctuations in land drainage and oceanic water. In the present case, however, the former appears to be the main cause. The decrease in specific gravity in autumn is caused by the rainfall at that season as shown by Nisida (1926) in the coastal waters of Korea. According to the Imperial Observatory, Kobe (1936–1937), the effect of the autumnal rainfall is perceptible even at Hatizyô-zima, an oceanic island where the seasonal change is least marked.

The decrease in specific gravity in spring is doubtless due to freshets of thawing snow, as is especially to be observed in northern Japan during the period from April to May (Kokubo, 1928, 1932, 1938) in Aomori Bay.

Such decreases in specific gravity in spring and autumn are sometimes found at one and the same station, as at Hamada, where a decrease in specific gravity occurs in April or May and where, after this has been compensated, a second decrease occurs in August, the latter being the more marked of the two (fig. 2 [9]). The same tendency is found yearly at Asamusi, where the autumnal decrease, normally negligible, is sometimes remarkable (fig. 2 [5]). At Hanasaki, although it is in Hokkaidô, no decrease in specific gravity was noted during 1932–1933, though in 1931 a marked decrease occurred in spring (fig. 2 [2]). This change may possibly be attributed to the quantity of snow in the district. Little or no autumnal decrease is perceived at Hanasaki and the other northern stations, owing to the scanty rainfall at that season.

Relationship between specific gravity and plankton diatoms.—On the score of locality, plankton diatoms tend to be abundant in inshore and scarce in offshore regions. Geographically considered, they are abundant in northern and scarce in southern waters. The specific gravity of sea water is likewise low in neritic or northern waters and high in oceanic or southern waters. Hence the attention of the investigator is likely to be drawn to an apparent parallelism between (low) specific gravity and diatom vegetations, and the late K. Yendo believed in the existence of a fixed correlation between these two factors. On further reflection, however, the fact emerges that usually a decrease in specific gravity is accompanied by an increase in nutriment from land drainage, consequently resulting in an increase of diatoms. The remarkable effect of nutriment has already been stated by many authors, for example, Marshall and Orr (1927) on the plankton of the Clyde Sea. It was demonstrated experimentally by Allen and Nelson (1910). The large number of diatoms in waters of low specific gravity may therefore be due to increased nutriment rather than to actual low salinity.

Allen and Nelson's (1910) study shows that *Skeletonema costatum, Biddulphia mobilensis,* and *Coscinodiscus excentricus* multiply freely in water which is twice diluted. *Coscinodiscus excentricus* is insensitive to low salinity and multiplies even in fresh water if a small amount of Mipuel solution is added. Kokubo and Tezuka (1938) found vegetation of *Skeletonema costatum* in a lake where the specific gravity of the water was 1.008. These results tend to show that diatom vegetation is largely due to nutriment and not to low salinity.

Considering the results of the present investigation from the view of specific gravity, plankton diatoms are abundant (more than 10,000 per liter) at seven stations (Takasima, Hanasaki, Senzima-suido, Rakuma, Asamusi, Yoiti, Mitaziri) where the specific gravity ranges from 23.94 to 25.01, the average being 24.34. In contrast to this, plankton diatoms are scarce (less than 10,000 per liter) at stations where the specific gravity ranges from 24.82 to 25.67. Results here given show that diatoms tend to be abundant in regions of low salinity and less abundant in regions of high salinity.

The fact that diatoms are abundant in conditions of low salinity is ascribable to the nutritive matter produced by land drainage. River influence may vary with locality, the nutritive content of the water being different in different rivers.

Transparency and color of water.—Transparency and water color are related to plankton as resultant rather than causal factors. These factors are varied by the quantity or kind of plankton, thus becoming a measure of plankton conditions. In certain special cases, however, as when the waters have some special color or minimum transparency, these factors affect the plankton causally. In the present investigation, these factors have been considered mainly in the former sense, as most of the stations showed normal values except at Mokuho, where transparency was definitely at its minimum.

TABLE 2
TRANSPARENCY VALUES

Station	Transparency		
	Mean (3 yrs.)	Range	Fluctuation
1. Rakuma	5.4	2.0–10.0	8
2. Hanasaki	6.1	3.0–12.6	9.6
3. Takasima	8.1	0.5–17.0	16.5
4. Yoiti	10.9	5.0–16.0	11.0
5. Asamusi	11.5	5.0–19.0	14.0
7. Huzan	3.7	1.8– 7.0	5.2
8. Mokuho	1.0	0.3– 1.8	1.5
9. Hamada	13.8	5.0–24.0	19.0
11. Mitaziri	10.2	5.5–15.0	9.5
12. Senzima-suido	4.8	2.0–13.0	11.0
13. Katōzima	13.1	9.0–15.0	6.0
14. Kanayama	15.6	5.0–25.0	20.0
15. Kagosima	11.9	7.0–22.0	15.0
16. Syaryôtô	3.0	3.0	....

The results of the present investigation show the mean value of transparency as given in table 2.

Table 2 shows that the mean value is highest (15.6 m.) at Kanayama and lowest (1.0 m.) at Mokuho. Such values are very small when compared with those obtained on warm, open-sea shores where a value as high as 50 meters or more is sometimes attained. Transparency, as is well known, shows a seasonal change. During the present investigation the most distinct change was observed at Kanayama, where the annual fluctuation was 20 meters, while at Mokuho it was 1.5 meters only.

In the neritic region transparency is highest when the land drainage attains its maxima and lowest when it attains its minima. According to Kokubo and Tamura (1932, 1938), transparency in Aomori Bay decreases twice a year, in spring at the time of thaw and in autumn when the rainfall increases. This was also the case at Asamusi, Yoiti, Huzan, and Mokuho during the present investigation.

It is already known that comparison of transparency and plankton volume shows that both factors are correlated. Such correlation is, however, not consistent enough to enable a precise comparison to be made. In the present investigation, therefore, only a rough comparison was made to determine the general tendency. This comparison showed that in 92 cases out of 171 transparency was low when plankton volume was high, but in 61 cases this relationship was not found, transparency being high when plankton volume was low. In the remaining 10 cases there was no definite tendency. Thus in the present investigation, too, the general tendency of plankton volume and transparency to change reciprocally was realized. The reason why such correlation is not closer may be due to the existence of secton and also to the optical factor, which has not been investigated.

The color of water as measured by Forel's scale is usually high in neritic regions and low in the open sea. Thus the values obtained in the course of the present work are relatively high on account of the littoral observations. The mean values of three years' observation are given in table 3.

TABLE 3
COLOR VALUES

Station	Scale Reading (No.) Mean (3 yrs.)	Range (No.)	Fluctuation
1. Rakuma	5.9	5.0– 7.0	2.0
2. Hanasaki	5.9	5.0– 7.0	2.0
3. Takasima	5.8	5.0–11.0	6.0
4. Yoiti	4.8	3.0– 6.0	3.0
5. Asamusi	4.6	3.5– 6.0	2.5
7. Huzan	7.4	6.0–11.0	5.0
8. Mokuho	6.3	5.0– 7.0	2.0
9. Hamada	5.0	3.0– 7.0	4.0
11. Mitaziri	5.2	5.0– 9.0	4.0
12. Senzima-suido	7.3	6.0– 9.0	3.0
13. Katōzima	4.8	4.0– 6.0	2.0

As may be seen from table 3, the highest mean value is found at Huzan and the lowest at Asamusi. The table also shows that fluctuation varies greatly among the stations. For example, at Takasima and Huzan the fluctuation ranged widely, No. 5 – No. 11, while at Mokuho and Katōzima it ranged only between No. 5 – No. 7 and No. 4 – No. 6, respectively. As will be noted from later statements, a wide range of fluctuation occurs at stations where plankton is found and a small range at stations where plankton is scarce.

Since color of water is related to quantity of plankton, it is naturally also related to transparency. Kokubo and Tamura (1932, 1938) showed that rise of color reading and decrease of transparency are closely related. According to these authorities (1938), a decrease of 2 meters in transparency corresponds to one degree of color reading. In the present investigation, also, the relationship was clearly shown, as may be seen from figure 3.

Plankton and oceanographic conditions.—It has already been indicated that change of plankton in the sea is due to a number of causes and that each of these causes may function as an accelerating or inhibiting factor, according to circumstances. In the natural state of the sea each factor varies from time to time and from one factor to another. This difficulty is always encountered when one tries to solve ecological problems from the study of one or more factors. In the present state of biology there may be no other way of solving the problem save by studying the effect of such factors in the experimental tank. Under experimental conditions it is possible to vary a certain factor while the other factors are fixed, thus making it possible to study the effect of each factor separately.

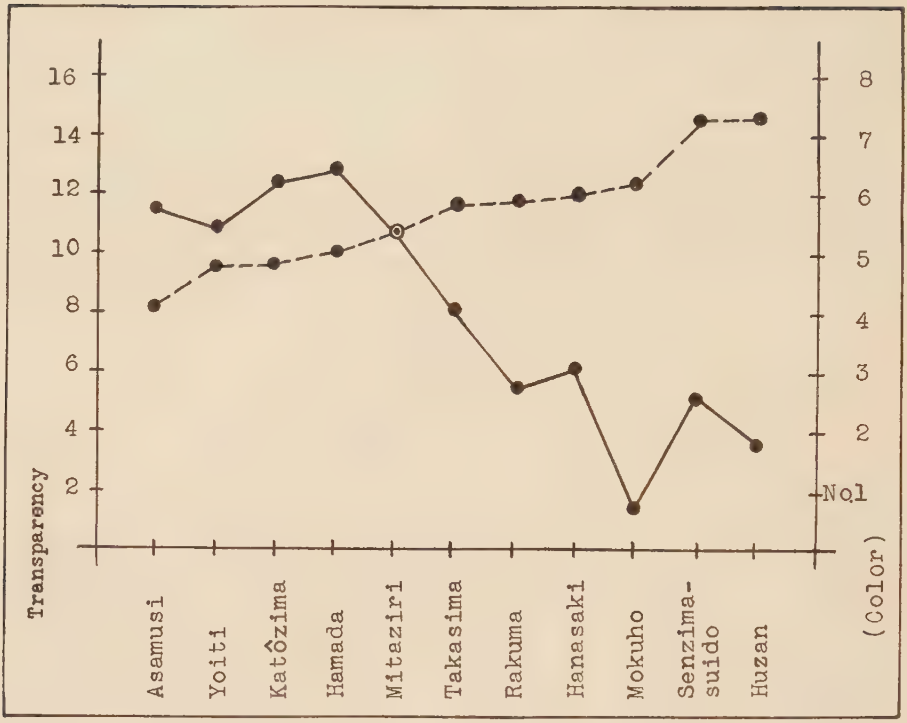

Fig. 3. Relationship of transparency and color. Unbroken line, transparency; broken line, color.

Oceanographic conditions which may govern diatom vegetation include (1) water temperature, (2) illumination, (3) nutriment, (4) pH and salinity, and (5) stability of water, that is, with reference to wind and current. With regard to the effect of these factors, it is generally accepted that rise of water temperature, enriched nutriment, increased illumination, and moderate current accelerate vegetation, while it is inhibited by converse conditions. When closely considered, however, the matter is not so simple, because each plankton shows its own particular adaptation to each factor, so that an increase in temperature does not necessarily accelerate vegetation, and also because one factor may function antagonistically to another.

As will be stated later, the results of the present investigation show that plankton is more abundant in the north than in the south. At the same time, however, it was found that the maximum abundance of diatoms does not occur in the coldest season. These facts seem therefore to suggest that temperatures above or below a certain degree are equally inhibitory to multiplication. On the other hand, it is also to be noted that the autumnal vegetation of diatoms begins with the decrease in temperature. In such a case the change of temperature functioned merely as a stimulant and was of secondary importance for vegetation, the prime factor being nutriment, which at that season is enriched by increased land drainage.

Turning to nutriment, it was found that at the stations which are rich in plankton (Takasima, Hanasaki, Yoiti, Rakuma, Huzan, Asamusi, Mitaziri) a rich supply of nutriment due to land drainage was to be presumed, while the stations where plankton was scarce seemed to be influenced by oceanic water lacking nutriment. From these facts the remarkable effect of nutriment which may sometimes surpass that of temperature may be surmised.

RESULTS OF QUANTITATIVE STUDY

The "Stich Probe" method of counting, usual in the study of plankton, was followed in the course of the present investigation and it is therefore impossible to estimate the amount of error in each count. This is undesirable when it is intended to count each specimen accurately, draw a probability curve, and compute the error and deviation, but it will be realized that this was physically impossible in a work like the present. The figures given in the present paper cannot, therefore, be taken as expressing more than a general tendency.

The species names of diatoms were identified by the simple method of examining the specimen under high magnification. No special treatment such as immersion in acid or imbedding in a special medium with high refractory index was employed. Further close examination will, therefore, increase the number of species to some degree.

KINDS OF PLANKTON

The plankton appearing in the present study may be enumerated as follows, in quantitative order: (1) Diatoms, (2) Dinoflagellata, (3) Tintinnoinea, (4) Silicoflagellata, (5) Copepoda, (6) Cladocera, (7) Copelata, (8) Hydromedusae, (9) Radiolaria, (10) Cyanophyceae, (11) Larval plankton.

Of these the most important groups were Diatoms and Dinoflagellata. In all cases these two groups governed the quantity of plankton and suggested their bearing upon the productivity of the sea. In addition, Tintinnoinea, Silicoflagellata, and Copepoda also had some quantitative bearing upon the total number of plankton; the other groups were of minor importance only.

QUANTITY OF PLANKTON

The quantitative results of the present study have been successively published in the *Plankton Journal* since 1931. From these results it appears that the greatest number found in any single collection was 5,312,275 per liter (number of cells) (dominated by *Skeletonema costatum*), at Hanasaki, June 1, 1931, and the least, 19 (*Euchaeta* sp.), at Hamada, December 1, 1932. Throughout all collections it was notable that no specimen was found to be totally lacking in plankton. This is certainly due to the fact that all collections were made in littoral regions.

The present results show that plankton is distinctly more abundant in the north than in the south. This tendency can be seen from table 4, in which the monthly and annual averages over three years are given. Figures 4 and 5 are graphical representations of the geographical distribution.

According to table 4, the number of plankton (per liter) ranges from a minimum of 3440 at Syaryôtô (Formosa) to a maximum of 339,581 at Takasima (Hokkaidô). In figure 5 the collecting stations were placed in accordance with the numerical order of plankton, the result showing that the stations are roughly in geographical order from north to south. From figures 4 and 5 can be seen the decreasing tendency from north to south with the rate of decrease. Rakuma (Saghalien), which should come first in the correct geographical order, came seventh, probably because of some local cause. Figure 5 also shows that Huzan (Korea) comes third in spite of its being farther south in geographical order. This can be accounted for by the boreal nature of the oceanographic conditions at Huzan, the cold water from the Japan Sea, and the fact

TABLE 4

Numbers of Plankton

Station	Month												
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Mean
1. Rakuma	861	1,280	7,424	191,779	51,959	48,516	3,330	1,550	2,163	3,278	5,075	4,770	26,832
2. Hanasaki	9,385	31,681	122,831	148,284	144,334	199,583	180,156	169,505	303,812	174,347	88,995	28,081	133,419
3. Takasima	6,317	9,109	30,539	220,148	6,946	3,473,418	11,162	65,560	47,996	177,064	16,646	10,064	339,581
4. Yoiti	2,991	7,609	48,212	25,432	6,722	25,603	1,965	4,631	90,129	95,200	8,676	6,573	26,979
5. Asamusi	10,090	68,480	92,741	11,182	65,941	38,872	25,816	38,639	22,864	33,347	21,929	14,117	37,002
6. Tateyama	4,300	......	4,170	......	......	......	......	......	......	......	......	......	4,235
7. Huzan	6,520	12,302	39,158	36,701	62,477	49,364	57,888	75,926	112,660	51,574	55,704	7,200	47,289
8. Mokuho	2,475	3,194	1,548	1,019	1,988	697	519	23,198	8,327	3,977	6,669	3,452	4,755
9. Hamada	3,660	12,400	3,936	7,374	5,446	4,149	3,865	8,306	8,518	27,469	26,568	4,457	9,679
10. Daityô	5,240	2,965	7,916	6,150	7,350	5,275	......	......	......	......	......	......	5,816
11. Mitaziri	2,651	......	......	36,530	53,714	14,204	4,784	15,762	6,848	6,312	12,359	10,200	16,336
12. Senzima-suido	......	......	......	......	......	1,957	6,155	59,606	106,655	55,679	18,660	......	41,452
13. Katōzima	1,484	6,302	16,377	5,669	13,360	9,996	12,003	9,374	8,467	15,632	20,502	2,531	10,141
14. Kanayama	2,222	2,641	19,510	7,112	14,554	18,916	2,730	4,259	2,777	1,012	423	1,238	6,450
15. Kagosima	12,284	......	15,839	1,022	338	234	186	186	......	......	......	......	4,299
16. Syaryôtô	8,657	9,825	1,500	451	5,477	2,394	1,935	1,469	3,406	932	......	1,797	3,440

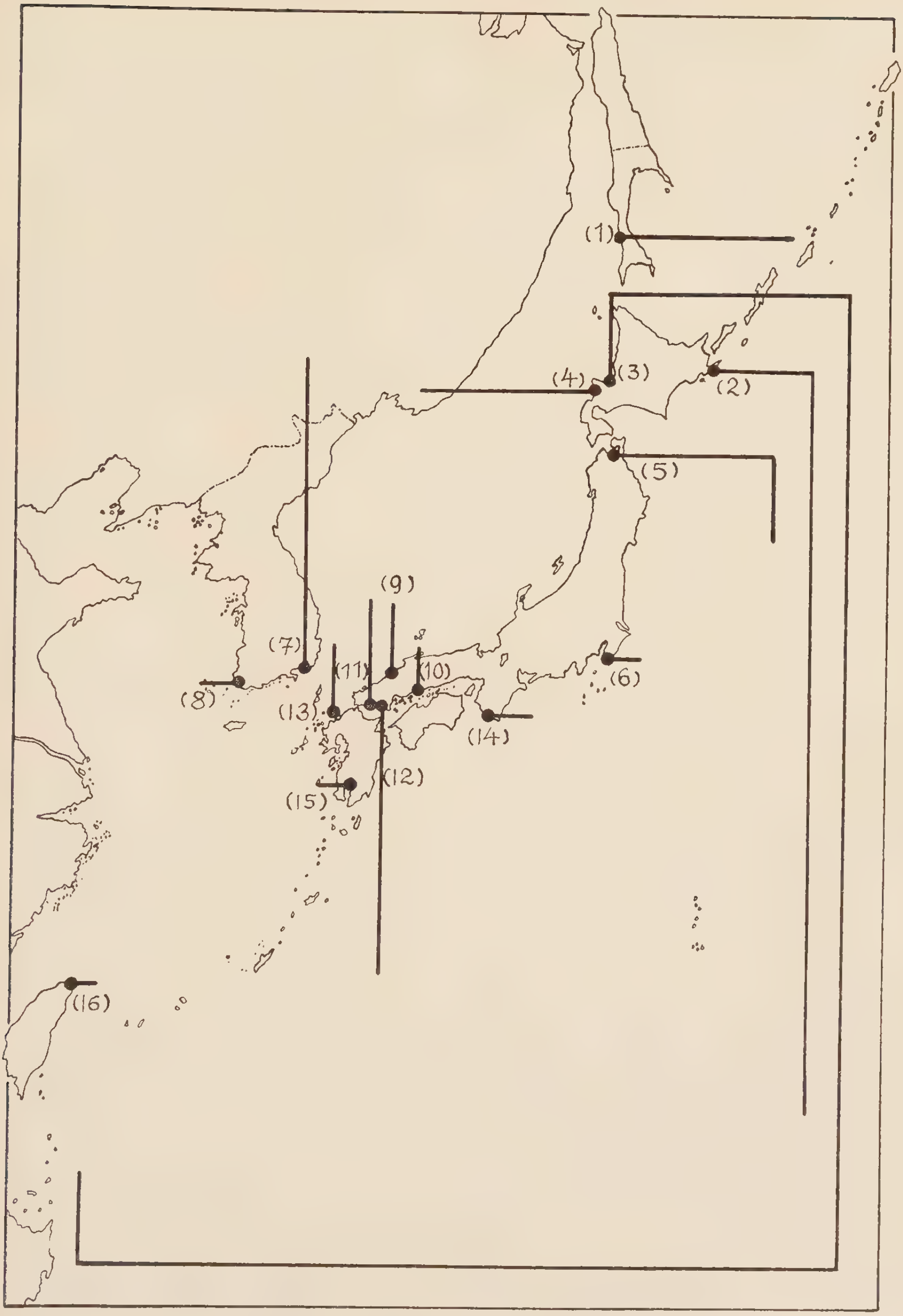
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Fig. 4. Geographical distribution of plankton in terms of quantity.
1 mm. = 1000 cells.

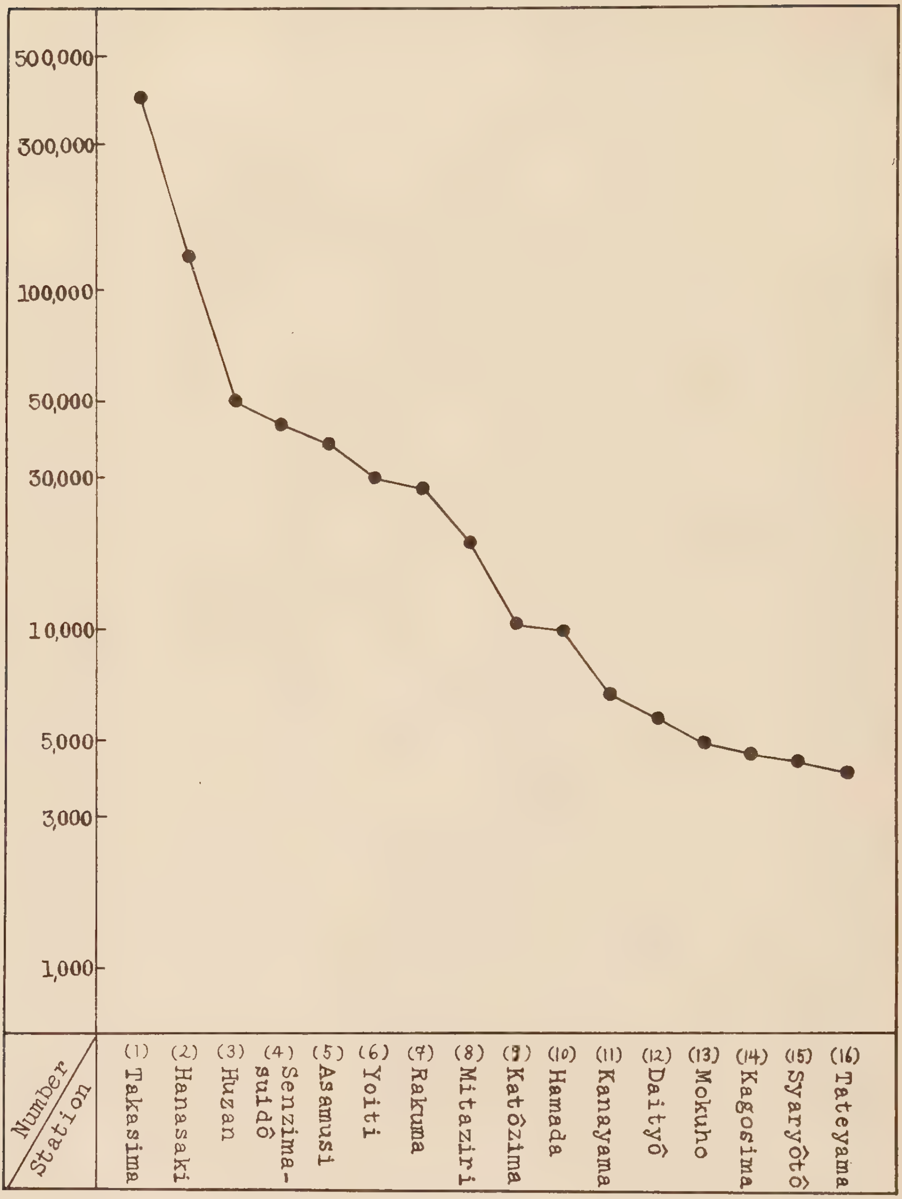

Fig. 5. Relationship between collecting stations and numbers of plankton.

that this station is influenced by the River Rakuto and the drainage of the city of Huzan. In addition to Huzan, the two southern stations of Senzima-suido and Mitaziri also rank high. This is doubtless due to their inland position.

Looking through the number of plankton as given in figure 5, it appears possible to divide the station into two groups, those with plankton numbering more than 10,000 and those with plankton numbering less than 10,000. The former group of stations naturally lies in the north and may be considered as representing the productive seas, while the latter group lies in the south and represents the barren seas.

Allen (1927*a*, 1928) studied the number of plankton diatoms in the inshore regions of California. His records show that in southern California the number of diatoms per liter often exceeds 1,000,000. The maximum record during 1921–1924 was 2,038,880 (weakly mean) at Hueneme on April 7, 1924. He states that plankton maxima are undoubtedly to be found in the north, but that in northern seas a maximum is always followed by a minimum, whereas in southern California the numbers are relatively equal throughout the year, so that the southern seas probably do not contain smaller numbers of plankton than the northern seas. The present results, however, show that in Japanese neritic regions plankton is distinctly more abundant in the north than in the south, as may be seen from table 4.

Seasonal change in number of plankton.—Table 4 also gives the seasonal change in the number of plankton at each station. From it four types of seasonal change can be recognized:

1) Numbers high in spring	Rakuma, Mitaziri, Kanayama, Kagosima, Syaryôtô
2) Numbers high in autumn	Mokuho, Senzima-suido
3) Numbers low during winter only	Hanasaki, Asamusi, Huzan, Hamada, Katôzima
4) Numbers vary irregularly	Takasima, Yoiti

It can be seen from the foregoing that at all stations where numbers are low during the winter only, plankton is generally more plentiful than at the other stations. On the other hand, it is also noticeable that the stations where large numbers of plankton are found either in spring or autumn are southern ones where plankton is generally scarce. At stations where plankton abound in summer and autumn and are scarce in winter only, numbers are naturally high, while at stations where plankton multiply in spring or autumn only the average will naturally be poor.

Diatoms: species.—The number of species of plankton diatoms found during the present study was about 160. This may be much less than the actual figure, as minute species may have been overlooked and counted as subspecies. Allen (1932) states that the number of species of plankton diatoms may be no less than 200. Akatuka, indeed, reported 202 species at Takasima, though some of these are not true pelagic forms. In an earlier record issued by Yendo (1905), 50 species of plankton were reported from Misaki. A little later, Okamura (1911) recorded 57 species of neritic plankton from various parts of Japan. In America, Gran and Angst reported 93 species from Puget Sound. Recently, Allen and Cupp (1935) found 127 species of plankton in the Java Sea.

Among the many species or genera of pelagic diatoms the number of main species which usually dominate the flora is relatively limited and of these some are common to almost all localities. When examined ecologically, however, the community or formation differs with the locality. In the course of the present investigation the following eight genera were quantitatively important, in particular the first two:

Genus *Skeletonema*
Genus *Chaetoceras*
Genus *Thalassiothrix*
Genus *Thalassiosira*
Genus *Nitzschia*
Genus *Eucampia*
Genus *Asterionella*
Genus *Rhizosolenia*

Diatoms: quantity.—In order to consider the quantity of diatoms, the yearly quantitative change will first be examined as given in table 5, in which the range of extreme change in each station is also given.

TABLE 5
Quantities of Diatoms

Year	Station											
	1 Rakuma	2 Hanasaki	3 Takasima	4 Yoiti	5 Asamusi	6 Huzan	7 Mokuho	8 Hamada	9 Daityô	10 Katōzima	11 Kanayama	12 Syaryôtô
	Annual Mean of Diatom Number											
1931	10,904	195,303	275,595	......	44,485	56,880	......	18,775	31,441	12,952	8,650	4,074
1932	......	99,612	......	......	20,207	83,718	1,363	8,020	......	......	......	......
1933	......	48,631	......	25,041	90,937	23,764	1,310	5,344	......	6,782	......	......
	Maximum of the Year											
1931	......	756,673	5,311,175	......	437,060	368,827	......	212,597	313,433	61,856	53,725	17,036
1932	90,482	434,620	......	24,012	90,579	538,756	7,566	58,976	10,450	19,508	......	......
1933	248,885	252,832	......	218,886	23,000	175,103	3,795	70,062	......	74,795	......	......
	Minimum of the Year											
1931	......	1,415	374	......	1,590	1,309	...	1,034	4,110	675	87	451
1932	478	1,761	......	336	1,120	1,038	74	17	1,680	50	......	......
1933	808	1,156	......	465	100	296	347	383	......	116	......	......

As will be seen from table 5, the number of stations at which collections were made regularly throughout three years is rather low, but as far as the data go it can be said that the quantity of plankton gradually decreased from 1931 to 1933. This trend can be plainly seen by examining the annual average given in table 5 for four stations, namely, Hanasaki, Asamusi, Huzan, and Hamada.

The highest range of change is naturally found at Takasima, where plankton was most abundant, 5,311,175 per liter. Other stations showing constant large numbers of plankton had also a fairly high maximum, mostly over 1,000,000. In contrast to this at the southern stations, where plankton was scarce, the maximum number ranged chiefly around several thousand. Taking next the minimum number at each station, the lowest value was that of 1.7 per liter, at Hamada. The minimum number was also low at the southern stations, but nowhere was there a vacant collection, a thing often met with on the high seas. In short, roughly 100 or fewer diatoms were usually found, even at the lowest minimum, the case of Hamada above mentioned being somewhat exceptional.

Diatoms: seasonal change.—As the plankton dealt with in the course of the present investigation consisted mainly of diatoms, the trend of the quantitative change of diatoms corresponded with that of the total plankton, which has already been mentioned. In order to show the seasonal change caused by diatoms only, however, table 6 was compiled. In this table the seasonal changes for each successive year are shown separately to facilitate investigation of their yearly tendency.

Looking through the seasonal change as given in table 6, the following five types may be recognized:

1. Where vegetation occurs twice, that is, in spring and autumn. Examples are Rakuma (1932), Yoiti (1932), Asamusi (1931), Hamada (1932), Huzan (1933), Katōzima (1931, 1933), and Syaryôtô (1931).
2. Where vegetation occurs once in spring, as, for example, Mokuho (1932), Daityô (1931), and Kanayama (1931).
3. Where vegetation occurs once in autumn, as, for example, Hamada (1931, 1933).
4. Where the spring vegetation lasts long and the autumn vegetation commences early with the result that vegetation ceases during the winter only, as, for example, Hanasaki (1931, 1933), Huzan (1931, 1932).
5. Where the change is irregular, as, for example, Yoiti (1933).

As to whether at a given station one or other of these five modes occurs regularly, it can be seen that at Hanasaki the number of diatoms is high throughout spring, summer, and autumn. This tendency would appear to be consistent as it occurred for three years at this station. As this tendency is caused by the combination of both the spring and summer vegetation, it can be stated that such change occurs in seas where diatoms are plentiful.

At Asamusi, vegetation occurred twice a year, in spring and autumn, though in 1931 the latter was not distinct. This seems to be the tendency of this station. At Huzan, vegetation continued from spring to autumn in 1931 and 1932, while in 1933 two vegetations, spring and autumn, were distinguished. As has been already stated, however, this station abounds in plankton and the former change may be a general tendency. A distinct spring vegetation was observed at Hamada in 1932, but the general tendency seems to be the autumnal vegetation observed in 1931 and 1933. At Katōzima the change in 1933 was somewhat irregular, but twice yearly vegetation as observed in 1931 and 1933 would appear to be usual.

Thus a tendency peculiar to any given station can perhaps be found if the attempt is made. But it will be seen from the foregoing statement that data are

TABLE 6

Station	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Mean
	1931												
1. Rakuma	......	......	......	......	......	......	......	......	......	......	......	......	......
2. Hanasaki	17,965	52,437	316,766	312,832	28,178	403,434	716,779	114,905	157,422	18,853	200,773	3,293	195,303
3. Takasima	4,793	1,406	31,144	219,525	5,375	2,737,241	9,515	64,885	41,156	168,211	14,025	9,858	275,595
4. Yoiti	......	......	......	......	......	......	......	......	......	......	......	......	......
5. Asamusi	2,126	25,876	262,214	24,038	28,066	16,248	31,660	44,433	30,445	42,433	23,381	6,888	44,818
6. Tateyama	370	......	......	......	......	......	......	......	......	......	......	......	370
7. Huzan	5,500	7,688	22,525	31,576	7,525	33,800	278,027	99,093	115,233	60,820	16,402	4,365	56,880
8. Mokuho	......	......	......	......	......	......	......	65,490	22,850	9,777	17,374	9,169	24,932
9. Hamada	......	3,556	5,415	10,082	5,391	5,990	2,542	21,420	1,829	41,951	106,449	1,901	18,775
10. Daityô	4,110	......	......	......	110,518	169,426	4,813	10,385	18,000	19,250	10,815	8,325	39,516
11. Mitaziri	......	......	......	36,482	107,045	5,434	9,111	15,445	......	10,679	......	8,472	27,524
12. Senzima-suido	......	......	......	......	......	......	......	......	......	......	......	......	......
13. Katōzima	......	3,622	43,035	9,171	16,910	9,435	2,518	17,327	13,687	23,970	1,120	1,674	12,952
14. Kanayama	2,083	2,547	29,560	6,572	13,953	27,880	14,925	3,020	665	1,077	372	1,129	8,640
15. Kagosima	11,453	10,721	842	307	228	131	......	......	......	......			3,814
16. Syaryôtô	8,644	9,736	1,426	451	5,352	1,909	1,815	1,877	7,807	1,720	......	......	4,074
	1932												
1. Rakuma	......	......	12,480	3,935	6,411	90,482	3,240	1,510	478	2,058	4,865	3,420	12,888
2. Hanasaki	3,718	13,723	36,438	79,756	67,589	214,531	140,263	132,169	192,521	237,725	40,080	36,825	99,612
3. Takasima	6,635	14,872	29,013	......	......	......	......	......	......	......	......	......	16,840
4. Yoiti	......	......	......	6,523	422	3,032	1,860	3,234	15,130	18,542	......	3,157	6,487
5. Asamusi	3,825	10,765	9,880	1,265	15,407	23,616	35,338	29,842	58,876	29,702	23,015	952	20,207
6. Tateyama	......	......	......	......	......	......	......	......	......	......	......	......	......
7. Huzan	8,285	16,910	48,475	25,481	40,642	275,320	39,673	106,337	234,075	24,476	179,088	5,854	83,218
8. Mokuho	4,277	5,527	163	1,110	372	465	270	1,448	933	549	774	471	1,363
9. Hamada	5,580	31,502	2,328	3,673	844	3,230	662	1,316	18,139	9,951	17,183	1,822	7,936
10. Daityô	3,450	2,815	9,550	5,828	6,550	5,100	......	......	......	......	......	......	5,549
11. Mitaziri	2,457	......	......	......	313	221	83	......	633	599	9,637	......	1,991
12. Senzima-suido	......	......	......	......	......	1,785	5,536	1,767	8,278	71,473	......	......	17,768
13. Katōzima	1,779	8,875	8,844	4,732	......	576	......	2,483	......	......	......	1,358	4,092
14. Kanayama	......	......	......	......	......	......	......	......	......	......	......	......	......
15. Kagosima	......	......	......	......	......	......	......	......	......	......	......	......	......
16. Syaryôtô	......	......	......	......	......	......	1,837	363	133	48	......	......	595

TABLE 6—*Continued*

Station	1933												
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Mean
1. Rakuma	808	1,156	2,083	285,813	9,692	5,167	......	......	......	......	......	......	50,787
2. Hanasaki	3,262	16,647	84,373	69,493	71,913	65,588	21,743	137,196	9,156	69,119	15,395	11,686	47,964
3. Takasima	......	......	......	......	......	......	......	......	......	......	......	......	......
4. Yoiti	2,772	7,501	48,037	43,433	9,816	25,459	705	5,574	11,962	159,746	6,367	9,122	29,208
5. Asamusi	20,169	3,277	4,055	5,473	27,486	15,590	3,158	6,209	6,563	1,331	952	6,783	9,094
6. Tateyama	......	......	......	......	......	......	......	......	......	......	......	......	......
7. Huzan	1,829	1,786	14,989	4,611	99,165	74,140	18,705	10,715	5,947	41,791	9,942	1,543	23,764
8. Mokuho	634	2,037	1,254	837	3,578	907	704	1,423	757	2,105	1,342	538	1,343
9. Hamada	1,163	1,311	1,837	6,200	1,118	3,083	1,090	1,193	1,824	8,468	35,530	1,315	5,344
10. Daityô	......	......	......	......	......	......	......	......	......	......	......	......	......
11. Mitaziri	......	......	......	......	......	......	......	......	......	......	......	......	......
12. Senzima-suido	......	......	......	......	......	......	......	29,714	173,171	33,114	16,993	......	63,247
13. Katōzima	751	2,544	2,306	1,041	2,286	17,912	2,813	4,341	1,062	6,210	39,177	939	6,782
14. Kanayama	......	......	......	......	......	......	......	......	......	......	......	......	......
15. Kagosima	......	......	......	......	......	......	......	......	......	......	......	......	......
16. Syaryôtô	......	......	......	......	......	......	......	......	......	......	......	......	......

not sufficiently consistent to enable any fixed law to be established. Indeed the irregularity of this connection is suggested not only by the present study but also by the results obtained by other authorities. Kokubo (1932), when studying diatoms in Aomori Bay during 1929–1930, found regular vegetation in spring and autumn. The extension of the work, however (Kokubo and Tamura, 1934), showed that in 1931 the vegetation was irregular and that in 1932 only a maximum was observed.

Allen's (1927*a*, 1928) work which is based on daily observations taken in southern California presents excellent data for studying the seasonal change of diatoms. In his study the change was represented by taking the weekly average throughout the year and his figures and graphs ought to, and actually do, express the actual change that occurred. And yet the change is not so regular. For instance, at La Jolla in 1932 vegetation occurred twice, in spring and autumn, and in 1921 summer vegetation only was observed, whereas in 1924 vegetation occurred three times, in spring, early summer, and autumn. At other stations, too, a similar tendency was observed. Davidson (1934) studied the seasonal change in the Passamaquoddy region of New Brunswick during 1927–1931. His results show that during the first three years vegetation occurred in spring only, but that during the following two years the change was irregular, vegetation occurring in summer and autumn or during spring and summer.

With regard to the seasonal change of diatoms, it has hitherto been believed that in northern neritic regions diatoms vegetate twice a year, that is, in spring and autumn, whereas toward the south, for instance in the Mediterranean, these two vegetations combine and vegetation occurs once a year only. This doctrine appears to have originated from a few early studies carried out in Europe. The fact that such is not always the case has been stated by many authorities other than those above cited. Now, therefore, the seasonal change may be concluded to be as follows. Diatoms vegetate either in spring or autumn or in both seasons, secondary vegetation often being observable between these two vegetations. It should also be added that which of these vegetations is the greater, or which of the changes may occur at one and the same station, depends on conditions. A definite change cannot therefore be expected at a definite station even if conditions are such as to be likely to cause it.

As stated above, the seasonal change of diatoms is neither simple nor regular, but variable and more or less irregular in character. This is because it does not depend upon any one oceanographic condition, such as temperature, in which the change is simple and regular. Consequently it follows that vegetation is prone to change according to the condition of such factors as nutriment, or light, in which the change is not always regular. Thus irregularity of vegetation can always be caused by the influence of temporary factors upon lasting regular factors.

General Remarks

The results of the present investigation point to the conclusion that, like oceanic plankton, the neritic plankton is greater in abundance in the north than in the south. This conclusion seems to have found support mainly from the European studies in which the plankton quantity of the northern Atlantic seas is compared to that of southern seas such as the Mediterranean; but the work which has most decidedly indicated it must be the report of Hansen's plankton expedition. Hansen's work was graphically represented by Schütt (1892), and thereafter Steuer (1910) further added to it the results obtained from aboard the S.S. *Holsatia*. These graphical representations made the matter of general interest, and the conclusion stated is now widely accepted.

In the Pacific, however, no such findings seem to have been made as yet, except for a few studies such as Allen's (1927*a*), which were made on the plankton of offshore waters of Alaska, and show greater abundance of diatoms in northern waters. Though the result of the present investigation is based on a study of littoral plankton, its general tendency toward showing that the abundance of plankton is greater in the north than in the south well accords with Allen's result (1927*a*). Such agreement between offshore and inshore plankton can be regarded as probable, as the fact that the vegetation of diatoms in offshore regions proceeds *pari passu* with that in inshore regions is well known. In this connection Allen's (1923) work also showed that the pier observations of plankton diatoms at San Diego accord well with the results of offshore investigations of the U. S. S. *Pioneer*.

The fact of the greater abundance of plankton in the north than in the south has repeatedly been stated by several authors. For interpreting this phenomenon Nathanson put forward the theory of ascending vertical current, while Brandt ascribed it to the distribution of denitrifying bacteria. Probably these theories may partly account for this phenomenon; but, as is well known, the nutrient salts such as nitrate, phosphate, and silicate do not show so distinct a distribution as that of plankton, so that this phenomenon may also partly be ascribed to the general marine physiology that in the north the silical metabolism is more vigorous under colder temperatures than under higher temperatures, just the opposite of calcium, which is more actively utilized under high temperatures than under low temperatures.

From what has so far been mentioned it is obvious that the productivity of the sea is greater in the north than in the south, because the diatoms which are the originators of primary food stuffs are produced in greater amount in the boreal region than in southern seas. Indeed the diatoms are the most important producers of the sea and are consumed by other plankton. Therefore, as was stated by Bigelow (1926), it is a fundamental truth that the whole system of animal life in the sea depends on the tiny unicellular algae (diatoms).

Moor (1914) investigated the productive power of diatoms in the Irish Sea. He calculated the amount of carbohydrate from the pH change of sea water. His result shows that about 8.8 milligrams per liter of carbohydrate were produced during the spring vegetation of diatoms. He states that this corresponds to a production of about 300,000 kilograms of dry organic matter per square kilometer of the sea. Recently Nielsen (1937) stated that at the four-meter depth off Helsingör about 130 grams of carbohydrate (glucose) were produced by photoplankton during one year (1932–1933). He further states that at Frederikshaven on the Kattegat 150 milligrams of carbohydrate per cubic meter is produced every month during the summer season. Of course such an amount may depend exclusively upon the quantity of phytoplankton, that is, diatoms, yet the latter amount (150 milligrams) can be said to be a fairly high value.

The productivity above stated is the production of plankton, but it may give an account for the fishery production to some extent. For, in general, it is true that in the seas rich in plankton the fishery production is also great. This is evidenced by the fact that in the benthos such as shellfish—for example, oysters and scallops—the more numerous the plankton, the better they grow. This is well indicated by the practice of shellfish culture. In this case, therefore, plankton production directly represents the fishery productivity of the sea. But as far as the nekton such as fishes is concerned this is not necessarily so. The seas rich in plankton do not always produce fishes in great amount. That is to say, there is a gap between the plankton and the fishery productivity. This is due to the ecological fact that most of the fishes do not feed directly on the diatoms, but feed on other diatom-feeding animals. Therefore it follows that where there are abundant diatom feeders there are abundant fishes.

In considering the amount of plankton as an index of productivity it should be noticed that the measure of plankton in such a case must not be temporary or occasional. To determine the productivity the measurement must be made throughout the year. In this connection Murray and Hjort (1912, p. 775) pointed out that the results of Hansen's plankton expedition convey no idea of the actual production of the ocean. On the other hand, in addition to the quantitative study, the rate of reproduction of plankton must also be taken into account, because the stronger the productive power is the more it will be utilized by fishes.

The relation between the quantity of plankton and fishery productivity is also made indefinite by the ecology of fishes. For instance, each fish has its own proper distribution, some fishes being unable to inhabit the seas rich in plankton. This fact shows that the distribution of fishes does not depend solely upon the food matter. Accordingly, there may be cases where the fishery productivity is not great in spite of the fact that there are abundant plankton. The present investigation also shows that at Hanasaki an unusual amount of plankton is found but the fishery productivity is not greater than in other seas.

Therefore the productivity of the sea can be considered in two steps. That is, primary importance must be attached to the plankton productivity, which is studied by the quantitative plankton method. The matter of secondary importance is fishery productivity, which is controlled to some extent by the plankton productivity, and can be predicted in some degree by the plankton study. But the latter productivity is also controlled by other ecological conditions, so that its determination must be made by other methods, such as fishery statistics or other biological studies.

SUMMARY

1. A quantitative study has been made of the microplankton collected at sixteen stations along the Japanese coast, ranging from Saghalien to Formosa, during the period 1931–1933.

2. The results of the present investigation point to the conclusion that, like the oceanic plankton, the abundance of the littoral plankton is greater in the north than in the south, the tendency being fairly distinct.

3. The tendency just mentioned suggests that the productivity of the sea is in general greater in the north than in the south. But, when considered more particularly, plankton production and fishery production do not always coincide, because of the difference of the ecology of animals.

4. The kinds of the plankton collected by the present method were: (1) Diatoms, (2) Dinoflagellata, (3) Tintinnoinea, (4) Silicoflagellata, (5) Copepoda, (6) Cladocera, (7) Copelata, (8) Hydromedusae, (9) Radiolaria, (10) Cyanophyceae, and (11) Larval plankton. Quantitatively, the first three groups are most important, the others following in the order given.

5. So far as the results of the present investigation are concerned, the number of plankton (number of cells per liter of water) ranged from a minimum of 19 (Hamada, September 27, 1931) to a maximum of 5,312,275 (Takasima, June 1, 1931).

6. When the numbers of plankton taken at each station are compared geographically, they are found, in general, to decrease from north to south. Discrepancies have apparently been due to local neritic conditions.

7. As the present investigation is limited to consideration of microplankton,

it is naturally dominated by the diatoms, and consequently the seasonal change is chiefly manifested by the diatoms.

From the observations of sixteen stations during three years it can be said that diatoms vegetate either in spring or in autumn, or in both these seasons and that secondary vegetation is often observable.

The seasonal change of diatoms is neither simple nor regular, as has so far been believed, but variable and more or less irregular. This is because the vegetation is prone to change in accordance with temporal neritic factors, such as, for example, nutriment.

8. The stations investigated in the present work can be divided into two groups, those with more, and those with fewer, than 10,000 plankton per liter; the former group of stations representing the productive seas, and the latter the barren seas.

9. As to the relation between oceanographic conditions and diatom vegetation, it can be said that change in the latter is apparently governed by elementary factors such as water temperature, but that at the same time it is also liable to change with other factors, as, for example, nutriment conditions or submarine illumination. This probably produces the temporal change in vegetation, thus making the seasonal or local change irregular.

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THE STUDY OF SPECIES FORMATION IN CERTAIN EUCALANUS COPEPODS IN THE NORTH PACIFIC

By Martin W. Johnson

In a preliminary circular sent out by the subcommittee on marine biology, the question was asked: "What should be the attitude of taxonomists with regard to closely similar organisms from different geographic areas?" For the zoögeographer and the taxonomist or biologist interested in relationships and racial development, the answer must be one demanding a detailed scrutiny of the organism and an exact record of its systematic position and geographic locality. The importance of this has long been recognized. Lohmann, in his study of plankton, is quoted by Steuer (1933) as stating that it will be particularly worth while to investigate the relationships that exist between development of subspecies and the organization of the races.

In an earlier report (Johnson, 1938) an analysis was made of the systematic position of certain Pacific offshore copepods commonly lumped more or less indiscriminately by some authors under the name *Eucalanus elongatus* without reference to varieties established by Giesbrecht (1892). In the report mentioned, the varieties *bungii* and *inermis* were raised to the status of species and a new variety, *californicus*, was established under *E. bungii*. In the present study, the importance of *E. inermis* can be discussed only briefly since only a few specimens have been taken and from data at hand it appears to be confined to a southern region not clearly connected with the northern group, though it does show structural affinities between *E. elongatus* and *E. bungii*.

Mori (1937), a Japanese investigator who also recognized that *bungii* should be considered a distinct species, gave it the specific name *giesbrechti*. However, in keeping with the rules of taxonomic procedure, the older variety name *bungii* must be retained.

In the 1938 report mentioned above, the then known distribution of these animals along the Pacific North American coast was charted and the probable route followed in the formation of the species was very briefly alluded to. In the interim since this publication, it has been possible to extend the distribution chart to include also a part of the Asiatic coast, thus increasing materially the known range of these important north Pacific copepods. This is made possible through the courtesy of Dr. H. Marakawa, a pioneer in the study of copepoda in Japan, who has supplied me with specimens collected at 54° 35′ N, 163° 24′ E, and Takamochi Mori, who kindly supplied specimens from the coast of Japan, and through the recent work of the latter dealing with pelagic copepoda from the neighboring waters of Japan. This is therefore an opportune time to thank these men and to present this additional information and fuller interpretation as a report of progress which may aid in further stimulating effort toward deciphering this and other similar riddles of marine zoögeography.

As shown in 1938, *E. elongatus* extends along the west coast of North America from near the Galápagos Islands (Giesbrecht, 1895) to Monterey Bay. Overlapping with it and extending from about 26° N (July 1939 collections) to Puget Sound, with its maximum numbers along the Californian coast, is *E. bungii californicus*. The type variety *E. bungii bungii* extends from Cape Mendocino (in small numbers at least) into Alaskan waters, the Bering Sea, and even into the lower reaches of the Arctic Ocean, where it is able to reproduce apparently successfully during July (Johnson, 1937). It is abundant off the Schumagin Islands, where at times it may constitute up to 55 per cent of the larger copepods.

If *E. elongatus* be considered phylogenetically the older of the species here discussed, and if the *bungii* varieties are derived from it, it is significant that in accordance with my previous observations: "The morphological characters separating the two forms of *E. bungii* are small yet definite and well defined, and it is interesting to note that morphologically *E. bungii californicus* is the one farthest removed from *E. elongatus hyalinus*[1] though geographically it appears from this general survey to be the only one of the two which is in contact with that species on this coast. This raises the question whether these relationships may possibly indicate the geographical route followed in the evolution of the varieties. Has *E. bungii bungii* been derived from *E. elongatus hyalinus* at its northern extension on the Asiatic coast, and has *E. bungii californicus* later split off from this northern branch?"

Information gleaned through direct comparison of the American material with the Asiatic samples mentioned above, and through a study of Mori's locations in his taxonomic report, now show that *E. elongatus* does indeed extend up the coast of Japan and that it is replaced in the northern range by *E. bungii bungii.* The material supplied by Dr. Marakawa from near Kamchatka contained only the latter species, and the material checked from the coast of Japan showed only *E. elongatus* as Mori intended. His taxonomic descriptions and figures do not touch upon the character separating the two varieties of *bungii*, but from so detailed a work one might justly consider that a failure to mention the point of difference would indicate a total absence of *E. bungii californicus* on the Asiatic coast.

In plotting Mori's locality records for *E. bungii bungii* it is to be noted that this form was taken only in the waters north of 40° N latitude, east and south of Hokushu where the cold waters of the Oyashio current abut upon the warm Kuroshio current. The samples supplied by Marakawa were taken off the east coast of Kamchatka, thus also in cold water, and though samples are wanting from between these locations, it is highly probable that a continuous distribution connects these points and extends eastward to unite with the known distribution off the American coast, thus forming a continuous area including the cold water immediately south of the Aleutian Islands. In plotting the Asiatic distribution of *E. elongatus,* the area involved extends from Formosa to the offshore waters at the northern end of Honshu below 40° N latitude.

The prevailing northward-flowing oceanic current on the Japanese coast, that is, the Kuroshio current, would transport *E. elongatus* northward to where this stenothermic warm water animal would constantly be pressed, along the outposts of its dispersion, into the colder, unfavorable waters of the north. It may, however, be expected to extend eastward with the main mass of warm water (North Pacific Drift) flowing across the Pacific toward the North American coast (Shott, 1935) and thus perhaps occur in small numbers, at least in sterile dispersion, at higher latitudes in the offshore waters along our coast where upwelled cold water is not too pronounced.

The exact origin of *E. bungii bungii* can of course not be determined with certainty, but the common character shown in the presence of two free segments in the abdomen proper places it nearest *E. elongatus* or *E. inermis.* As far as known, however, it is now widely separated geographically from the latter species, unless there be contact in the deep cold water of the tropics or subtropics; but such equatorial submergence has not been shown in this case.

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[1] This variety name established by Giesbrecht (1892) to distinguish his varieties of *E. elongatus* is no longer needed.

There is some difficulty in considering *E. bungii bungii* as being derived from the original stock through *E. bungii californicus* on the American coast; structurally this would require a loss of two distinctive setae on the second basis of the mandibular palp in *californicus* and then subsequently regaining these in *bungii* (see Johnson, 1928, figs. 21, 22, 23). The armature of the second basis of the palp is distinctive even in the nauplius stages (Gibbons, 1936, fig. 1; Johnson, 1937, p. 97). However, the intermediate relationship of *E. inermis*, through absence of lateral points on the fifth thoracic segment, may be important in this connection and needs further investigation.

A most likely explanation seems to be a route of species development associated with the great clockwise circulation in the North Pacific, in which the frontiers of the species are constantly pushed into environments more and more unfavorable to the stenothermic original stock but suitable to new strains. Other workers have shown evidences of the great importance of general oceanic circulation and temperature in the formation of planktonic species. In a review of the distribution of cold-water species, Russell (1935) considers the prevailing deep-water circulation of the Atlantic as favoring formation of the larger number of antarctic and subantarctic species and deep-sea genera as contrasted with the smaller numbers in the arctic and subarctic regions. See also Steuer, 1925, 1933.

To what extent a similar type of analysis will apply to other planktonic animals of the Pacific, we are unable to say. Our relative lack of knowledge of the pelagial region of the North Pacific is expressed in the following statement (translated) by Sven Ekman (1935) in his zoögeographic discussion of the northern cold-water plankton: "On account of our rather small knowledge of faunistic conditions of the North Pacific pelagial, we shall have to be satisfied with a discussion of the better known North Atlantic and of the Atlantic portion of the Arctic Ocean."

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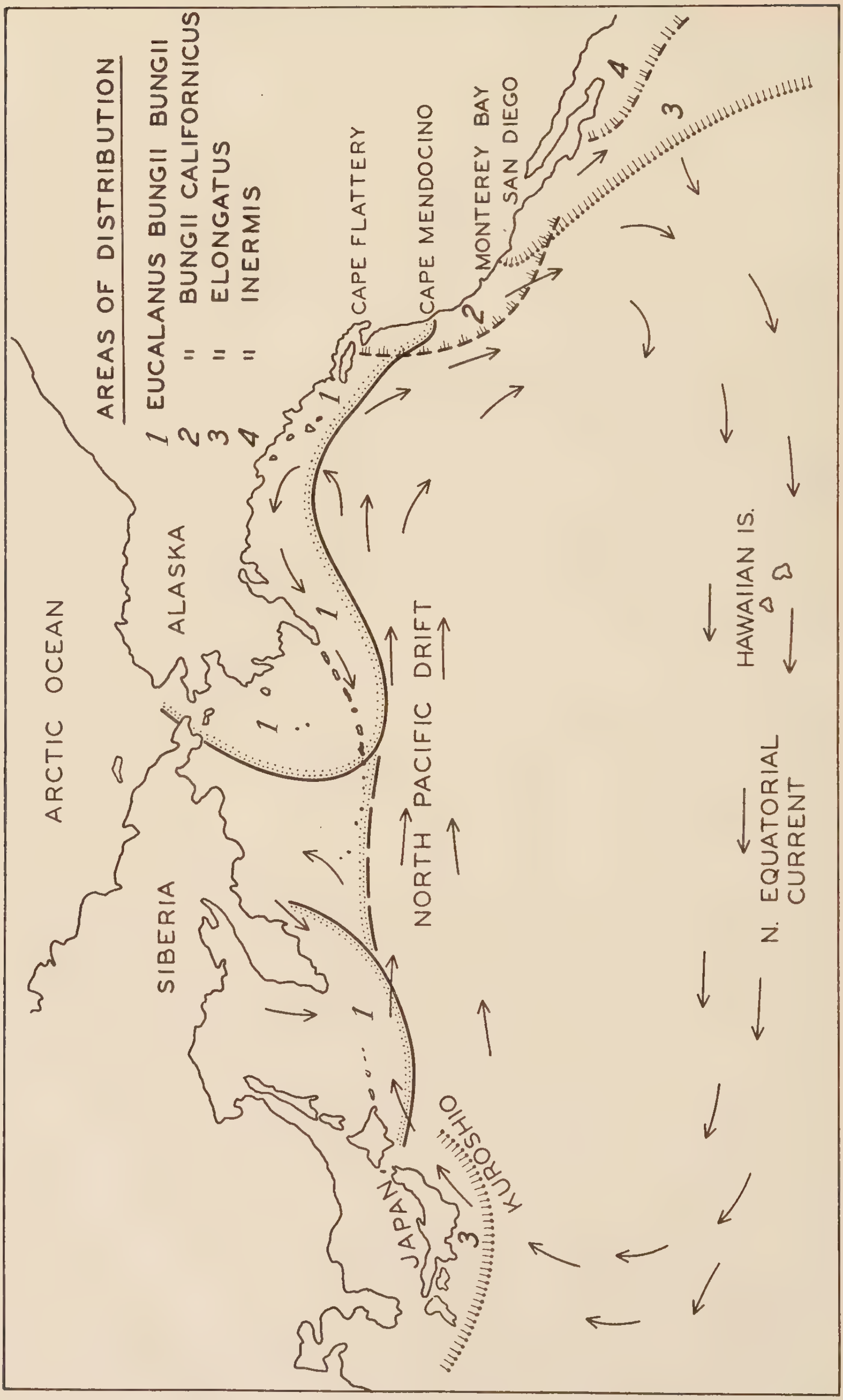
AREAS OF DISTRIBUTION
1 EUCALANUS BUNGII BUNGII
2 " BUNGII CALIFORNICUS
3 " ELONGATUS
4 " INERMIS
ARCTIC OCEAN
SIBERIA
ALASKA
CAPE FLATTERY
CAPE MENDOCINO
MONTEREY BAY
SAN DIEGO
NORTH PACIFIC DRIFT
HAWAIIAN IS.
N. EQUATORIAL CURRENT
JAPAN
KUROSHIO
1
1
1
1
1
2
3
3
4

Map showing distribution of certain *Eucalanus* copepods in the North Pacific.

RECENT PLANKTOLOGICAL WORKS IN JAPAN

By Hiroaki Aikawa

Planktological investigations are carried out mainly at the Fisheries Experimental Stations of Tôkyô, Husan, Kirun, and Hokkaidô. Samples are collected around Japan widely along about 130 sectional lines. Plankton is quantitatively collected with Kitahara's open net vertically from 50 m. to the surface and also with Marukawa's closing net from 100 m. to 50 m. S. Kokubo uses the pump method and large water bottle of 2 liters' capacity for quantitative collection. K. Matudaira determines the volume of plankton by the displacement method, and Kokubo by the settling method after collecting with water bottle.

Oyasio and Kurosio are the important ocean currents which affect the neritic region around Japan. The Tusima current is, so to say, the Kurosio in the Japan Sea, and the Liman current is the Oyasio. They are characterized planktologically as follows.

The Kurosio group is generally represented by Desno-, Styli-, or Tripos-plankton. The diatom communities of these planktons are similar to one another, and the invariable components are *Climacodium biconcavum, C. Frauenfeldianum, Dactyliosolen tenuis, Ditylium sol, Gossreliella tropica, Guinardia flaccida, Hemialus heibergii, Planktoniella sol, Streptotheca indica,* and many species of *G. Rhizosolenia.* In addition to them, *Amphorella, Epiplocylis, Proplectella, Rhabdonella, Tintinnus,* and *Xystonella* of Tintinnodes are all good indicators of the Kurosio group. Radiates occupy more than 10 per cent of all zoöplanktons.

The Oyasio group is usually monotonous in composition and large in quantity. *Calanus plumchrus, Euchaeta japonica,* and *Metridia lucens* form often monotonous patches in several areas in the cold-water region. Considered in relation to the diatom community, Phaeoplankton is generally representative, and sometimes Trichoplankton also occurs. In the former plankton, *Phaeoceros* is prevalent and mixes a little with *Rhizosolenia semispina.* In the latter plankton, *Thalassiothrix longissima, Corethron hystrix,* and some *Coscinodiscus* species are abundant. Phaeoplankton is the summer type of the Oyasio group, while Trichoplankton is the winter type. *Parafavella, Cyttarocylis,* and *Ptychocylis* also indicate the Oyasio group.

The Tusima current group has many species in common with the Kurosio, and the Liman with the Oyasio group, although the neritic character becomes more or less distinct in these groups in the Japan Sea. The Tusima current group is influenced by the Liman current group in winter and its aftereffect is recognizable even in spring, while the Liman current group is also affected by the Tusima current group during summer.

The Yellow Sea group is rather neritic in character, although it is always influenced considerably by the Kurosio group. All these oceanic groups are uniform and stable in both composition and quantity throughout the vast area for a considerable length of time.

S. Kokubo has collected samples from 16 coastal stations around Japan since 1933 and the results are published in the *Plankton-Zihô* (*Plankton News*) every year. The neritic plankton group is characterized by the following points: (1) phytoplankton generally occupies more than 80 per cent of all plankton; (2) adult and larval planktons are rich in kind, but radiates and copepods never attain such high percentages as in the oceanic groups; and (3) among diatoms, subg. *Hyalochate* is nearly always the leading one, although the simple flora is formed either successively or abruptly by such diatoms as *Skeletonema costatum*, *Chaetoceros* spp., *Thalassiothrix nitzschioides, Paralia* sp., and *Eucampia zoodiacus*. Diatoms show two maximal reproductions in a year, and the maximal number of individuals markedly changes each year.

Lastly, concerning the inverse relation between the quantities of phyto- and zoöplankton, H. Aikawa, against two famous theories put forward by A. C. Hardy and H. W. Harvey, holds a similar view with E. Steemann Nielsen and showed statistically the slower development of zoöplankton to retard the appearance of its maximum as compared with the time of phytoplankton maximum.

There are only a few systematic works on plankton, and we can only mention the recent works in this line as follows: (1) Dinoflagellata — T. H. Abe (Sci. Rep. Tôhoku Imp. Univ., 4 (Biol.), Vol. 2; *ibid.*, Vol. 10); (2) Tintinnoinea — Y. Hada (Journ. Fac. Sci. Hokkaidô Imp. Univ., 4 (Biol.), Vol. 5, *ibid.*, Vol. 6, Sci. Rep. Tôhoku Imp. Univ., 4 (Biol.), Vol. 7); (3) Copepoda — O. Tanaka (Jap. Journ. Zoöl., Vol. 7, Nos. 1, 2); (4) Mysidacea — N. Ii (Jap. Journ. Zoöl., Vol. 6, No. 4, *ibid.*, Vol. 7, Nos. 1, 2); (5) Brachyuran larva — H. Aikawa (Rec. Oceanogr. Wk. Jap., Vol. 9, 1).

MARINE PROTOZOA OF THE PHILIPPINES

By Hilario A. Roxas

The general thesis that smaller plankton, both animal and vegetable, is practically the sole food supply for young marine fishes requires no further proof or argument. Studies of the stomach contents of these animals prove it beyond any doubt. The plankton, likewise, serves many species of fishes when adult. Such fish as the herrings, sardines, and mackerels are primarily plankton feeders. Even such big sea animals as the whales and a number of sharks, as well as many bivalves, the oysters, for example, subsist exclusively on plankton organisms.

Authorities agree that nearly 90 per cent of commercial fishes have pelagic, that is, surface-floating eggs. Only very rarely does a fish hatched from a buoyant egg ever grow large enough to descend to the bottom in the precise locality where the egg that gave it birth was spawned. A young fish, after having exhausted the yolk material of the egg, has to rely on microscopic plankton organisms available at its place of hatching for the continuation of its existence. It therefore becomes essential that we know the amount of surface plankton in our waters in order to determine the amount of surface pelagic fish life that it can sustain. No quantitative plankton studies, however, can be made unless they are preceded by at least some sort of systematic qualitative studies. It is sad to admit that the Philippine seas are a *mare incognitum* as far as the microörganisms of the plankton are concerned.

The earliest work on the protozoa of the plankton in the tropical Indo-Pacific waters was that of C. T. Cleve (1901). His material was collected by different individuals in 1897, 1899, and 1900 on a route from Aden to Java and on a route from 45° S, 22° E, to 30° S, 91° E; from the last point to 2° N, 94° E; and in the Malay Archipelago, from Billiton to Timor. This work was followed by those of Weber Van Bosse and Schmidt (1901), Schroder (1906), and Ostenfeld (1915). In later years, Matzenauer (1933) wrote on the dinoflagellates of the Indian Ocean; Nielsen (1934) and Bohm (1936) wrote on the dinoflagellates of the southern and western Pacific Ocean, while Marshall (1934) wrote on the Silicoflagellates and Tintinnoinea of the Great Barrier Reef. In spite, however, of several works on the marine protozoa of the tropical eastern, western, and southern Pacific, the China Sea, and the Indian Ocean, no work has been done on the protozoa of the seas in and immediately around the Philippines.

The present paper is a preliminary report on local marine protozoa, based on plankton materials obtained weekly from the Bureau of Science Binakayan Experimental Station at Bacoor Bay (Manila Bay), and from one collection from the Marine Biological Station at Port Galera Bay, Mindoro. The study was originally undertaken with the end in view of finding out the relationship between the rate of growth and fattening of oysters and the volume of planktonic organisms available from the water. Ultimately it is hoped to tie up the seasonal abundance and movement of herrings and sardines, which are very important Philippine fisheries. It is here reported not as a finished work, but merely as an invitation to other investigators to collaborate in the huge task of solving our very numerous oceanographic and marine problems. Problems concerned with temperature, pressure, direction and force of wind, amount of rain, sunshine, cloud, specific gravity of the sea water, hydrogen ion concentration, tides and currents, sediments, and turbidity of the water, as well as numerous chemical, bacteriological, and botanical materials, still await the attention, time, and energy of our scientists. All these data are needed if we are to know the cause or causes of the distribution, abundance, and horizontal as well as vertical migrations of plankton organisms and their effect on the seasonal distribution and abundance of the various fisheries.

Plankton collections were made with a tow net of fine bolting cloth, No. 20, of 176 meshes to the inch, from an outrigger banca. The plankton collected from each haul is transferred into a small wide-mouthed bottle with a sufficient amount of water and fixed in a 10-per cent formalin solution. Qualitative studies are done in the laboratory.

The survey at Bacoor Bay and Port Galera Bay so far has yielded sixty-eight species of marine protozoa. Of these, thirty-four belong to the order Dinoflagellida of the Class Mastigophora (Flagellata), and thirty-two belong to the order Heterotrichida of the Class Ciliata. The genera represented are as follows:

Peridiniopsis	1 species
Diplopeltopsis	1 species
Gonyaulux	2 species
Peridinium	11 species
Podolampas	1 species
Ceratium	11 species
Phalocroma	4 species
Dinophysis	3 species
Tintinnidium	3 species (two new)
Leprotintinnus	2 species (one new)
Tintinnopsis	10 species (two new)
Codonellopsis	1 species
Coxliella	1 species
Favella	4 species (three new)
Epiplocylis	3 species
Metacylis	2 species (both new)
Petalotricha	1 species
Rhabdonella	4 species (one new)
Tintinnus	1 species

The above-named unicellular animals are the larger forms that do not readily pass through an ordinary silk bolting cloth and do not readily disintegrate soon after the haul. A big number of salt-water and brackish protozoa, however, are so minute and delicate that they have to be collected with the use of filter paper and have to be treated with a standard fixing agent soon after collection. Protozoa of the latter category have not yet been touched.

The protozoa, numerous and abundant as they are in our bays and seas, rank second only to the diatoms in importance as food for other aquatic animals and fishes. We are, therefore, hoping that in the near future our rich marine unicellular plant fauna will also attract the attention of our botanists.

SYSTEMATIC ENUMERATION OF PHILIPPINE MARINE PROTOZOA

Class MASTIGOPHORA

Order Dinoflagellida

FAMILY PERIDINIIDAE

Genus *Peridiniopsis*
    P. asymmetrica Mangin
Genus *Diplopeltopsis*
    D. minor Lebour
Genus *Gonyaulux*
    G. polyoedra Stein
    G. digitale Pouchet
Genus *Peridinium*
    P. conicoides Paulsen
    P. latissimum Kofoid
    P. leonis Pavillard
    P. subinerme Paulsen
    P. depressum Bailey
    P. divergens Ehrenberg
    P. obtusum Karsten
    P. venustum Matzenauer
    P. africanoides Dangeard
    P. curtipes Jorgensen
    P. pellucidum (Bergh)
Genus *Podolampas* Stein
    P. bipes Stein
Genus *Ceratum*
    C. furca (Ehrenberg)
    C. candelabrum (Ehrenberg)
    C. pentagonum Gourret
    C. dens Ostenfeld & Schmidt
    C. fusus (Ehrenberg)
    C. tripos (O. F. Muller)
    C. breve Ostenfeld & Schmidt
    C. macroceros (Ehrenberg)
    C. trichoceros (Ehrenberg)
    C. contrarium Gourret
    C. molle Kofoid

FAMILY DINOPHYSIDAE

Genus *Phalocroma*
    P. rotundatum Claparede & Lachman
    P. cuneus Schutt
    P. mitra Schutt
    P. doryphorum Stein
Genus *Dinophysis*
    D. miles f. *indica* Cleve
    D. caudata Kent
    D. hastata Stein

Class CILIATA

Order Heterotrichida

FAMILY TINTINNIDIDAE

Genus *Tintinnidium*
    T. primitivum Busch
    T. cylindrica sp. nov.
    T. ampullarium sp. nov.
Genus *Leprotintinnus*
    L. nordquisti (Brandt)
    L. tubulosus sp. nov.

FAMILY CODONELLIDAE

Genus *Tintinnopsis*
    T. bacoorensis sp. nov.
    T. butschlii Daday
    T. gracilis Kofoid & Campbell
    T. loricata Brandt
    T. manilensis sp. nov.
    T. major Meunier
    T. mortensenii Schmidt
    T. radix (Imhof)
    T. tocantinensis Kofoid & Campbell
    T. turgida Kofoid & Campbell

FAMILY CODONELLOPSIDAE

Genus *Codonellopsis*
    C. ostenfeldi (Schmidt)

FAMILY COXLIELLIDAE

Genus *Coxliella*
    C. longa (Brandt)

FAMILY CYTTAROCYLIDAE

Genus *Favella*
    F. simplex sp. nov.
    F. philippinensis sp. nov.
    F. elongata sp. nov.
    F. azorica (Cleve)

FAMILY PTYCHOCYLIDAE

Genus *Epiplocylis*
- *E. exquisita* (Brandt)
- *E. ralumensis* (Brandt)
- *E. undella* (Ostenfeld & Schmidt)

FAMILY PETALOTRICHIDAE

Genus *Metacylis*
- *M. hemisphaerica* sp. nov.
- *M. kofoidi* sp. nov.

Genus *Petalotricha*
- *P. major* Jorgensen

FAMILY RHABDONELLIDAE

Genus *Rhabdonella*
- *R. amor* (Cleve)
- *R. spiralis* (Fol)
- *R. brandti* Kofoid & Campbell
- *R. fenestrata* sp. nov.

FAMILY TINTINNIDAE

Genus *Tintinnus*
- *T. perminutus* Kofoid & Campbell

Descriptions of New Species

Tintinnidium cylindrica sp. nov.

Lorica tubelike with a medium thick wall and a distinct hyaline structureless collar. Shoulder of bowl at right angles to collar. Height of collar about 16 times in the total length. Cavity of uniform diameter, equal to diameter of collar, which is about 19 μ. Aboral end rounded, usually with an irregular break (resulting perhaps from detachment). Wall coarsely granular with few coarse agglomerations. Total length 126 μ; greatest diameter 33 μ; thickest portion of wall 8μ.

Type locality.—Manila Bay, Philippines.

This species differs from *T. ampullarium* in being more slender, in having thinner wall, and in having the shoulder of the bowl at right angles to the collar instead of sloping.

Tintinnidium ampullarium sp. nov.

Lorica flask-shaped, with a thick, finely granular wall and a distinct hyaline structureless collar. Shoulder next to collar sloping. Height of collar 10 times in the total length. Cavity of uniform diameter equal to oral diameter. Aboral end somewhat flattened, always with irregular opening (perhaps a break resulting from detachment). Oral diameter 17 μ; total length about 100 μ; greatest diameter 45 μ, which is about twice diameter of aboral region, thickest portion of wall about 14 μ.

Type locality.—Manila Bay, Philippines.

Leprotintinnus tubulosus sp. nov.

Lorica long, in the form of a simple tube, basal portion not at all expanded; oral diameter about 3.9 in the total length; wall thin, with fine agglomerating particles. Lorica about 140 μ long and 37 μ in diameter. Specimens showing transverse budding are often met with.

Type locality.—Manila Bay, Philippines.

Tintinnopsis bacoorensis sp. nov.

Lorica campanulate with an expanded bulbous fundus and a spreading oral rim. Between the fundus and the flaring collar is a cylindrical middle portion, the neck. Oral rim rugged, about 1 in the total length; diameter of neck about 1.75 in the total length; bulbous portion about 1.37 in the total length. Wall with thick agglomerations of various sizes. Total length 63.8 μ; oral rim diameter 63.8 μ; neck 29.6 μ; and fundus 41.9 μ.

Type locality.—Manila Bay, Philippines.

This differs from *T. mortensenii* in having a bulbous fundus distinctly set off from the central cylindrical portion, which has a smaller diameter. In the figure of Kofoid and Campbell as well as that of Okamura such a differentiated neck is not visible.

Tintinnopsis manilensis sp. nov.

Lorica tall, campanulate, with an irregular oral opening about 1.2 in the total length and a convex rounded expanded fundus. Bowl narrowest at its middle, which is visibly in the form of a neck; oral margin of lorica in the form of a flaring collar, diverging to about 45 degrees; neck with a diameter 3 and a length also 3 in the total length; bulbous portion with a diameter 2.2 in the total length; wall with thick agglomerations of various sizes and shapes. Oral diameter about 67 μ; smallest transdiameter of neck 26 μ; diameter of fundus 37 μ; total length 81.5 μ.

This species is closely allied to *T. butschlii*. It differs from the latter, however, in having a distinct narrowed portion of the bowl, here called the neck, which is visibly set off from the bulbous terminal fundus. It is almost twice as long as *T. bacorrensis*.

Favella simplex sp. nov.

Lorica campanulate, widest at oral region, its total length about 2.17 oral diameters, oral rim smooth; oral region with almost straight sides and bowl almost cylindrical to about 0.46 of its length; aboral region with slightly convex sides and contracting to about 55°; aboral horn about 0.32 oral diameter, with a slight construction at middle, tip pointed. Wall double, thin and structureless; oral diameter 70 μ; total length 152 μ; aboral horn 25 μ.

Type locality.—Manila Bay, Philippines.

Favella philippinensis sp. nov.

Lorica cylindrical, stout, its length about 1.7 oral diameters; oral rim slightly serrate or denticulate, with two narrow rings; orally, bowl cylindrical for about 0.70 of its length, with a slight nuchal constriction; aboral horn region more or less conical, contracting to about 70°; aboral horn about 0.43 oral diameter in length, and a pointed cone (20°), tip pointed, wall very smooth and finally aleolar. Oral diameter 108 μ; length excluding horn 215 μ; aboral horn 47 μ.

Type locality.—Manila Bay, Philippines.

Similar to *F. panamensis* Kofoid and Campbell in many respects, except in the fine serration of the oral rim. A number of specimens were seen in which the lorica is slightly wider (oral diameter about 1.5 in the length).

Favella elongata sp. nov.

Lorica cylindrical, long, its length about 2.6 oral diameters; oral rim irregularly serrate with two very narrow rings without a definite nuchal constriction; anteriorly, bowl cylindrical for about 70° of its length; aboral region more or less rounded, contracting gradually to about 80°; aboral horn proportionally small for the size of the bowl, 0.38 oral diameter, with rounded tip. Wall alveolar double with striae between. Oral diameter 115 μ; length of bowl about 299 μ; aboral horn 43 μ.

Type locality.—Manila Bay, Philippines.

This is much longer than *F. philippinensis*, and the aboral region is more rounded.

Metacylis hemisphaerica sp. nov.

A small species with stout basketlike lorica, oral diameter about 1.09 in the total length; collar with height about 4.3 in the total length, slightly contracting with four spiral laminae; bowl rounded abapically; wall hyaline. Length about 45 μ; oral diameter about 41 μ; greatest diameter of bowl about 48 μ.

Obtained from Port Galera Bay, Mindoro, Philippines.

Differs from *A. corbula* Kofoid and Campbell in being shorter but wider and in having a much rounded bowl abapically.

Metacylis kofoidi sp. nov.

Lorica stout, basketlike; oral diameter 1.2 in the length; collar very low, about 6 in the length, wall slightly contracting and with 3 spiral laminae; bowl rounded but with a slight knoblike protuberance abapically; wall hyaline; length about 45 μ; oral diameter about 37 μ; greatest diameter of bowl about 45 μ.

Type locality.—Port Galera Bay, Mindoro, Philippines.

Differs from *M. hemisphaerica* in having lower collar with only 3 laminae, in being narrower, and in having a knob of the bowl abapically.

Named after Professor Charles A. Kofoid, protozoölogist, University of California.

Rhabdonella fenestrata sp. nov.

Lorica small with oral diameter about 16 in the total length; oral rim with a pronounced gutter between the inner and outer laminae; bowl cylindrical toward oral half, then becoming subconical, first about 65°, then contracting to about 32° to form short, blunt pedicel about 2.5 in the oral diameter; ribs about 3.5, very prominent with a slight counterclockwise spiral; one row of well-developed fenestrae between two ribs. Total length about 80 μ; oral diameter about 48 μ.

Type locality.—Port Galera Bay, Mindoro, Philippines.

SUMMARY OF RESULTS OF TWENTY YEARS OF RESEARCHES ON MARINE PHYTOPLANKTON

By W. E. Allen

I suppose that not the least important of the results of twenty years of work of any kind is its demonstration of merit for the methods and equipment used. At any rate, a number of visitors and correspondents have indicated their understanding that the measured water method of collecting, involving the use of the Allen Closing Bottle for subsurface sampling, and the short silk net for filtering, has been fundamental in the success of quantitative phases of phytoplankton investigations at the Scripps Institution of Oceanography.

Although quantitative studies on marine diatoms and dinoflagellates have been given primary attention in all the major researches on phytoplankton at the Institution in a period of more than twenty years, the desirability and necessity for a good taxonomic foundation for these researches has been recognized throughout. It is true that in the preparatory studies of 1917 and 1918 most of the time had been devoted to determining the identity of species belonging to these groups in the southern California region, but it is also true that vexing problems of identification continued to exist or to arise after initiation of the permanent program in 1919. As a result of these conditions considerable improvement in classification has continued through the twenty-year period, culminating in 1939 in a monograph covering marine plankton diatoms of the East Pacific, contributed by Dr. E. E. Cupp. In this work she includes 160 species representing 51 genera, numbers fairly suggestive of the taxonomic characteristics of the population. Out of this number only about 30 species have ever reached numerical prominence in Institution collections. Less is known about the species of dinoflagellates, but only about 10 forms have ever been excessively prominent. Still, two or three of them have been responsible for the most striking discoloration ("red water") ever produced by phytoplankton in the sea water near the Scripps Institution.

Something has been learned concerning the ranges of occurrence although no careful examination has been made of the records for that purpose. For example, our collections have not shown large numbers of armored dinoflagellates north of Monterey although it is possible that the densest populations of diatoms occur in latitudes far higher than that. Certainly the largest of any in Scripps Institution collections were taken much farther north, notably off Gray's Harbor, Washington. Probably individual species of the two groups show this difference in tendency even more strongly, but only enough attention has been given to the matter to find that among diatoms the genus *Thalassiosira* is more prominent in Alaskan waters than it is south of the Columbia River, that *Cerataulina* and *Guinardia* are more prominent in collections from Mexican waters than from those north of San Diego, and that *Chaetoceros debilis* Cl., *Nitzschia seriata* Cl., and *Skeletonema costatum* (Grev.) are likely to reach great prominence in any latitude.

Dinoflagellates have never been found in large numbers more than twenty miles from shore, although Institution records include several notations of large numbers of diatoms found at various levels from the surface to fifty meters' depth at stations fifty miles from shore, or more. Without careful attention to the matter, it appears that a few species, especially the diatoms *Chaetoceros concavicornis* Mangin and *C. atlanticus* (Schütt), are more likely to be found offshore than alongshore. Certainly the greatest numbers of both these species have been found in offshore catches. Doubtless careful examination of the records for that purpose would show similar differences in some of the less prominent dinoflagellates as well as among other diatoms where they have escaped notice.

Chaetoceros concavicornis Mangin has been shown to be even more characteristic of subsurface depths than it is of offshore waters, but no other species of either diatoms or dinoflagellates has revealed so definite a tendency to live below the surface. It is entirely possible that some species of both diatoms and dinoflagellates may be found to have this tendency if our records are scrutinized for that purpose; for example, the diatom *Eucampia zoodiacus* Ehr. seems to do better below the surface although it is sometimes found in abundance at or near it. However, the impression which I get from my long acquaintance with the material is that species doing well at the surface at one time or place may not be able to thrive there at another time or place. So also with respect to any particular depth down to fifty meters. Doubtless the reversals or oscillations of relative prominence of species at different levels are sometimes dependent upon differences in tolerance of conditions found at particular levels at particular times and places. Almost all boat series which include subsurface catches show positively that largest abundance of diatoms at stations in water more than fifty meters deep is likely to be at levels from twenty to forty meters below the surface, sometimes one species and sometimes another contributing most to the total. The species having greatest numbers at thirty meters is often different from the species having largest numbers in a thinner population at the surface at the same station, but these ranks in prominence may be reversed at some other station. As yet we have not had time to learn how far our records go toward affording solutions for these and a number of other problems of occurrence of phytoplankton at different levels.

At the Scripps Institution pier, we have found at some time in the twenty years at least a few representatives of almost every species of diatoms known to occur in the East Pacific. Furthermore, it has been surprising to me to find that waters far from the open sea, like those of the Alexander Archipelago in Alaska and the Gulf of California in Mexico, appear to be just as likely to produce any designated species as is any other region. Certainly, most of the species prominent in the open sea in their latitudes are represented in collections from these relatively isolated regions. Therefore, it seems reasonable to say that no significant localization of species of phytoplankton is recognizable in the East Pacific, even regional limitations of occurrence being unimpressive.

It is fairly certain that a number of species of both diatoms and dinoflagellates have strong tendencies to appear only in one season of the year, but the relationship has not been worked out in detail for southern California seas. After collecting was stopped at the Alaskan station at Scotch Cap in the Aleutian Islands in 1933, it was studied for a few of the leading species by Dr. Cupp. She found that few specimens of diatoms of any kind were to be taken in the winter months, *Biddulphia aurito* (Lyngb.) being the one observed in most years. From April to August a considerable number of species was represented in most of the five full years of collecting, several of them reaching their largest abundance of the year in that period. *Asterionella japonica* Cl. was one of those which reached maximum abundance after August.

Perhaps I should not pass from this cursory survey of outstanding results of our imperfect study of relationships of species without referring to "red water," although we have given no intensive study to that phenomenon. All our collections of organisms from water contrastingly colored red (or a color passing for red) show that the discoloration is caused mainly by superabundance of one species, although accompanying species may themselves be far more abundant than usual. In La Jolla Bay, with the single exception of 1938, "red water" has been caused by the small dinoflagellate *Prorocentrum micans* Ehr. In that year the notorious genus *Gonyaulax* took precedence, *G. polyedra* being the species which reached excessive numbers, as it had not done in that locality since 1916. North and south of San Francisco, *G. catenella* Whedon has made its genus notorious by its responsibility for "mussel poisoning." So far as I know, it has not been recorded from any locality except those along the coast from Monterey Bay, California, to Coos Bay, Oregon. Now, in phytoplankton collections considerable distances from shore, I have just found it (identified by Whedon) in large abundance over a large area in the northern third of the Gulf of California and causing "red water" reported north of Angel de la Guardia Island by Director H. U. Sverdrup of the Scripps Institution on March 16, 1939, on the "Gulf Cruise" of the Institution research ship *E. W. Scripps*. In some casual collecting done by me alongshore on the coast of Washington in 1938 I found "red water" consisting of almost pure cultures of diatoms, *Aulacodiscus kittoni* Arn. (Copalis Beach) and *Asterionella kariana* Grun. (Long Beach). Doubtless "red water" presents the most vulnerable point for attack on some of the problems of species prominence and excesses of abundance, perhaps those of whole diatom or dinoflagellate populations also, but as yet we have made no extensive and comprehensive effort to organize and conduct such an attack.

Because to us it seemed more important to have a good foundation in general knowledge of populations and of the conditions under which populations exist in the sea, our primary attention has been given to whole populations in all series of collections since the phytoplankton work was given full standing as an Institution activity in 1919. Probably it will be best to discuss diatoms and dinoflagellates separately to avoid confusion.

Except for the Gulf of California series just mentioned, dinoflagellates never appeared to have much importance in catches taken offshore, even at stations only five and ten miles from the Institution pier. Therefore it may be supposed that whatever importance they have as components of populations of phytoplankton is narrowly restricted in southern California seas. However, the trends of their occurrence, distribution, and numerical fluctuations are well worth studying for whatever light they may throw on all kinds of problems of fertility of the sea. Some of these trends are remarkably like those of plankton diatoms. Perhaps most important of our results is establishment of the fact that the productive period for plankton dinoflagellates fluctuates around the twentieth week of the year, some years earlier and some years later, with the tendency to be early a little stronger at the La Jolla station than it is at Point Hueneme, more than one hundred miles farther north. Increases ("pulses") of abundance may occur at any time of year in southern California, but in most years they are longer and their production is higher in the interval between the tenth and thirtieth weeks, mid-March to early August.

I have been much interested in the very clear evidence that exceptionally warm years are unfavorable for dinoflagellates. The years 1926 and 1931 were such years, and production was poor at both stations in both of them. Inasmuch as 1926 is also on record as a year of shifting of fish populations to the north, it appears probable that this would have been a favorable year for observing the relationship between biological conditions and some of the recognizable chemical and physical conditions most closely allied with temperature. Certain evidence not so clear suggests that there is a five-year (possibly also a ten- or twenty-year) periodicity in dinoflagellate productiveness, a five-year period of inferior production including the very low year of 1926. Of course, we need the evidence of many more years before we can evaluate that suggestion.

To those who may have thought of conditions in the ocean as being so nearly uniform that the routine of life must be rather monotonous, it may seem somewhat shocking to know that our records show no two years alike in the twenty, no two months alike, and no two weeks alike. Continual change is the order of nature as much in the sea as it is on land, weather and many other influences playing their part in the eternal shifting of relationships. With nearly twenty years of daily observations behind me, I find it amusing when I see an account of the work of some student of nature who has learned the normal routine of life in a larger or smaller space on sea or land by an intensive study conducted through a few weeks or months or even years, and on a relatively small number of organisms.

Our records show that armored dinoflagellates may be extremely numerous at times, literally millions of them in each liter of water. On the other hand, it is shown just as clearly that they rarely appear in numbers greater than tens of thousands per liter. Because of the rarity of their production in large abundance, I have come to consider a thousand per liter as a fairly good showing for this group in ordinary catches, even alongshore. For that reason an abundance of millions per liter appears to me to be more significant than it is for the diatoms. That is to say that I think it possible that a dense swarm of the one might be more favorable for intensive study than a like swarm of the other because of the contrasts in activity or in the kinds of response to certain influences in denser and thinner populations.

Over the twenty-year period diatoms show a strong tendency to be most productive at about the same time as the dinoflagellates. However, a greater difference is discernible between the two stations at La Jolla and Point Hueneme, the fluctuation of productivity being around the fifteenth (or seventeenth) week at La Jolla and the twentieth (or twenty-second) week at Point Hueneme. There is also more irregularity at both stations in the appearance of highly productive pulses, one at La Jolla in January reaching over a hundred thousand cells per liter and several in tens of thousands occurring in winter months in the twenty years. In fact, February was the most productive month at La Jolla in 1920, one of the best years for diatoms.

The warm-water years of 1926 and 1931 were unfavorable years for diatoms, although possibly a little less so than for dinoflagellates. At any rate, there was more difference in the effects at the two stations, Point Hueneme producing much larger numbers through more than half of each year and about the same for the remaining time.

The records for diatoms show even more clearly than those for dinoflagellates the risk of drawing wrong conclusions from too little evidence in nature. For example, the weekly averages of daily catches for the first three years at La Jolla are mostly larger than those for corresponding weeks at Point Hueneme, and the year totals are larger. Surely one might be excused for concluding that La Jolla was the more productive station. Unfortunately for this view, Point Hueneme was far in the lead for the next four years and has been in the lead (or very nearly so) for every year up to 1938, when La Jolla came up strongly again. Also in the first ten years no week averaged higher than tens of thousands and few were above thousands at either station in January and December. Surely it might be supposed that light production would always occur in those months. But in December, 1932, La Jolla showed a last week average of more than 200,000 cells per liter, which carried over through the first week of January, 1933. Again in 1936 and in 1939 La Jolla produced high week averages in January. No less impressive in dealing with plankton diatoms is the increase in accuracy of understanding of the data obtainable by a daily frequency of collecting or observation. In our records for one pulse which were analyzed several years ago it was found that a complete change in leading species occurred near the middle of the pulse although the graph for the total population of diatoms showed no break in the curve. In reality, the occurrence of this pulse was based on the overlapping occurrence of pulses of two species, one succeeding the other in numerical dominance. Many times, in making up week averages from daily records (both for total populations and for individual species), observations made only once a week would have missed the large catches, missing also any indication of a distinctive pulse, not to mention many other incident phenomena. The unavoidable conclusion is that attempts to coördinate and correlate chemical and physical data with records of changes in activity or productivity of diatoms are likely to be grossly misleading if based on observations made at intervals longer than one day. Certainly they are not even dependably suggestive.

Extremely low production of diatoms tended to appear in August (La Jolla only), November, and December, but week averages of less than one hundred cells per liter for some weeks in other months may be found in different years, rarely and irregularly. A remarkable feature of this matter of low production of diatoms is that the thirty-second week of the year (August) was invariably on or very near the lowest limit of production for eleven successive years at La Jolla, although August was not notably deficient at Point Hueneme in most of those years. Apparently this strange condition is due to some climatic (or similarly general) condition which was operative at La Jolla and not at Point Hueneme. Such vagaries as this are especially interesting to me because of the possibility that they may be clues to important differences in conditions governing production at the two stations. After 1932 the distinction was less prominent.

Although the range of production of diatoms resembles that of dinoflagellates by extending from nothing to millions per liter for single catches at both piers, the general aspect of productivity is such that one expects at least some hundreds of diatoms per liter in a catch at any time of year, and some tens of thousands per liter in the generally productive period from March to July. Also, the general appearance of the records indicates that week averages of hundreds of thousands per liter are to be expected in some part of the period in most years.

Incomplete studies of food-chain relationships of diatoms (and dinoflagellates) have indicated direct use by sardines and mussels, but no approach to determination of values has been made.

In oceanographic literature it has become almost a maxim that higher latitudes are more productive of marine life than others. Diatoms, in particular, have been selected by various authors to illustrate their assertions that this is true. From the first, this view has been held in doubt at the Scripps Institution, although not contradicted. Our attitude has been merely that a sweeping generalization of this importance requires positive proof. So far as we have been able to deal with this problem, our results to date have strengthened our doubt, although we do not think that enough evidence of the right kind has been accumulated either for or against the idea. We hoped to get pertinent information by establishing a subarctic daily collecting station at Scotch Cap Light in the Aleutian Islands, but observations carried over parts of eight years (five full years) have yielded indications so directly contrary to that idea that we cannot accept their evidence except for supplementary use. Apparently the Scotch Cap station is in one of those localities rarely if ever characterized by large production of diatoms. It is true that Scotch Cap may be fairly representative of high latitudes because of a productivity near the average, but we need more evidence from highly productive localities as well as from poorly productive ones before we can form a dependable idea of what diatom production in high latitudes really is. By many observers too much reliance has been placed in cursory observations on populations which may have existed for only a few days or weeks and then only at surface levels. No true comparison can be made until observations are carried through a series of years at a number of stations in both high and low latitudes at levels from the surface to fifty or sixty meters, by sampling with high frequency at not less than ten-meter intervals. Aside from the relative thinness at Scotch Cap, the Scripps Institution has other records bearing on the question. Two cruises by the United States Coast and Geodetic Survey in Alaskan waters yielded surface collections which showed positively that extremely large numbers of diatoms were produced in certain localities, relatively few, however. Cruises by other ships as far south as Peru have obtained surface catches showing that at a number of points between California and the equator diatoms may appear at times in numbers exceeding a million cells per liter. That is to say, so far as we have been able to obtain evidence, high production of diatoms at the surface is not restricted to high latitudes. Off the California coast some of our largest catches of diatoms have been obtained at twenty to forty meters below the surface. High latitudes never have too much light at the surface and at best there is enough obliquity of the rays to cause rapid reduction of penetration of light. In low latitudes light is never too little and there is never serious interference with light penetration on account of obliquity. For these physical reasons alone it seems that relative productiveness of high and low latitudes needs thorough investigation before positive conclusions are reached one way or the other.

As early as 1926 the Institution found at stations no farther than five and ten miles from its pier that diatoms might be almost or quite absent from the surface although present in large abundance at one or more levels sampled below. In that year large numbers were found at the forty-meter level of the ten-mile station when only a few were at the surface. In 1927 at the five-mile station large numbers were found at thirty meters when the numbers at the surface were negligible and on another day much larger numbers were found at thirty and forty meters with small numbers appearing at levels from the surface to thirty meters. In this connection may be mentioned again the risk of drawing positive conclusions on limited evidence. In 1926 the ten-mile station was most productive, all levels considered, suggesting the idea that waters offshore were more productive, especially at lower levels. In 1927 the five-mile station was much more productive, collecting in both years being done in June and July.

On six cruises of 1938, sailed on alternate months from February, covering territory from Cape Arguello to San Diego, the evidence was fairly consistent throughout that better production of diatoms occurred at twenty or more miles offshore than within ten or fifteen miles of shore except for two highly productive stations in June near Santa Cruz and San Miguel islands. It was found also that the largest abundance was more frequently below than at the surface at single stations, although the surface level yielded largest numbers at some stations on some cruises. Collections of notable size were taken as far as one hundred miles from shore, thus showing definitely that wide spaces as well as considerable depths must be included in investigations of phytoplankton production and the conditions regulating it. From the same cruises we have strong evidence, also, that the seasonal differences in production of diatoms offshore correspond very well with those of most years as revealed by daily catches at inshore stations, the tendency being to greatest production in the April to June period. Unfortunately most of the cruises were made at times of slack production inshore or on the decline of an inshore pulse. If the time of each cruise could have been made at exactly the time of an inshore pulse, the larger numbers in the offshore catches might have made it easier to trace resemblances with confidence. However, the resemblances between seasonal changes of abundances at inshore and offshore stations are so close as to make it appear certain that inshore collections correctly indicate seasonal changes in production for the whole territory in most years, if not in all. Inasmuch as 1938 was the most productive year, or nearly so, at both La Jolla and Point Hueneme, it is probable that offshore production was also unusually high. In the thinly productive years of 1926 and 1931 it might have been difficult to trace any kinds of relationships.

Other investigators of phytoplankton may be interested in the fact that more than fifty papers have been published dealing directly with the phytoplankton material accumulated by the Scripps Institution in twenty years and that these have been supplemented by fifteen papers dealing with it less directly. Most of these papers are out of print, but some are still available for exchange.

Although a number of other things might be said about the results obtained or in process of being obtained by twenty years of phytoplankton researches at the Scripps Institution of Oceanography, I think that enough may have been said to indicate that no matter how busy we have been and how many problems we have attacked with variable success, there is still plenty to do. I close with a simple list of the more prominent or more significant series of collections and studies up to date. At the Institution pier daily collections have continued for twenty years; at Point Hueneme for nearly twenty years, to be closed out soon. Daily collections at Scotch Cap ran for eight years, at the Farallon Islands for five years, at Balboa, California, for three years, at Oceanside, California, for five years, and at a few other points for some months before being closed out. A number of short cruises by the Institution in local waters yielded some valuable data before Director H. U. Sverdrup instituted the bimonthly cruises of 1938, carried to seaward from several points on the California coast. In 1939 a cruise to the Gulf of California obtained valuable data, levels to sixty meters' depth being regularly sampled, yielding nearly three hundred and fifty catches. A cruise somewhat like those of 1938 but covering two hundred miles to sea in a half-dozen lines between the Columbia River and Cedros Island has just been completed, bringing in about five hundred catches which will be examined soon. In earlier years the United States Coast and Geodetic Survey not only collected for the Institution in Alaskan waters but also in the California region. The United States Navy contributed a series of collections made between California and Australia. The late E. W. Scripps gave two or three series of collections made by his yacht. Also the Institution has made use of collections contributed by Captain G. Allan Hancock of Los Angeles and by Templeton Crocker of San Francisco, as well as some others.

PLANKTON INVESTIGATIONS AT THE UNIVERSITY OF WASHINGTON

By Robert C. Miller

Plankton investigations at the University of Washington owe their inception to Professor Trevor Kincaid, who developed this field in connection with the establishment of a College of Fisheries at the University in 1919. During the twenty years since he has offered one of the few formal courses in plankton work available in American universities, resulting in the training of a number of capable young investigators.

Among students trained under Kincaid was M. W. Johnson, who carried on a systematic investigation of the plankton at the (then) Puget Sound Biological Station at Friday Harbor, over a period of years, beginning in 1923. His studies of the seasonal distribution of plankton and of the life histories of selected organisms were supplemented by investigations of the physical and chemical conditions of the water by T. G. Thompson and others, resulting in a series of important contributions (Thompson, Johnson, and Todd, 1928; Johnson and Thompson, 1929; Thompson and Johnson, 1930; Johnson, 1930, 1932, 1934*a*, 1934*b*).

The investigation of plankton received a fresh impetus and a new direction from the visits in 1928 and 1931 of Professor H. H. Gran, of the University of Oslo, who conducted a taxonomic survey of plankton diatoms of Puget Sound (Gran and Angst, 1931), participated in a study of diatoms in relation to physical and chemical conditions in sea water (Gran and Thompson, 1930), and trained a number of students in the use of Lohmann's centrifuge method as modified by Gran for the quantitative study of phytoplankton.

The method introduced by Gran has been utilized especially by L. D. Phifer (1929, 1933, 1934*a*, 1934*b*, 1934*c*) in a series of studies of the phytoplankton of the San Juan Archipelago. Phifer has also (1934*d*) described a method for continuous collection of phytoplankton from a ship under way, and collaborated in a study of seasonal variations in the chemical and physical properties of surface waters in relation to plankton and other factors (Phifer and Thompson, 1937).

The possibilities of plankton investigation were greatly increased by the establishment in 1930 of the University of Washington Oceanographic Laboratories (with which the Puget Sound Biological Station became merged), and especially by the launching of the Motorship *Catalyst* in 1932.

The lines of investigation pursued have been closely interwoven and mutually complementary. In general the investigation of phytoplankton has been under the direction of Phifer, while Kincaid, the writer, and their students have devoted particular attention to the zoöplankton; naturally it has proved neither practicable nor desirable completely to dissociate the two fields of work. A program has been laid out for the systematic collection of plankton at regular intervals at selected localities over a period of years. A point is made of taking plankton in such a way that the results obtained can be correlated with physical and chemical data obtained at the same time by other members of the oceanographic staff.

The writer has introduced for analysis of the whole plankton a method which has been gradually improved and which offers a relatively rapid method for quantitative work. Samples are taken by means of vertical hauls through a specified distance, with use of a modified Hensen net rigged in such a way that it can be closed at any desired depth. The whole sample is washed carefully into a jar and a measured amount of formaldehyde is added. Subsequently the sample is shaken up, a 10-ml. portion is removed for counting, if desired, or for future reference, and the remainder is subjected to successive determinations of displacement volume, dry weight, and ash.

A major problem usually encountered in plankton work is that samples are collected a great deal faster than they can be analyzed, so that the embarrassed investigator is threatened with being crowded out of his laboratory by the steady accumulation of his material. The method here outlined has the advantages of permitting storage of reference samples in homeopathic vials instead of large jars or bottles, and of quickly making available significant quantitative results (volume, weight, ash) for correlation with chemical and physical properties of the water.

The method has proved satisfactory in practice, and has already yielded a considerable body of quantitative data, which will become increasingly valuable as the same localities are visited from month to month, as projected, over a period of years, in connection with the regular operations of the Motorship *Catalyst*.

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DISTRIBUTION OF FISH IN THE TROPICAL PACIFIC

By Albert W. Herre

In a discussion of the distribution of fishes in the tropical Pacific, as in all problems of any magnitude, many factors must be considered. Unfortunately, in this particular problem some of the most important factors are but little known. It is easy to contrast some of the more outstanding differences between the eastern and western parts of the Pacific. The western Pacific is notable for its vast number of islands, reefs, and shoals, while a glance at the map shows the eastern Pacific to have very few islands. The western Pacific has warm water and a relatively high temperature prevails; as we travel eastward the air becomes cooler and the water has a relatively low temperature. This is true off the coast of both North and South America. The Galápagos Islands have the lowest temperature of any place on the equator at sea level, a result of the Humboldt current. The western Pacific is remarkable for its number and variety of fishes and has the greatest number of kinds of fishes in the world, while the eastern Pacific is relatively poor in variety and number of species.

As in other regions, we may group the fishes roughly into fresh-water and marine species. The latter, as all know, are rather loosely divided into shore fishes, pelagic fishes, and abyssal fishes. We need not consider the last-named, since they are nearly all of very wide distribution, occurring in all temperate and tropical seas. This is because conditions at the depths where they live are uniform everywhere. Most pelagic fishes are likewise circumtropical in distribution, and are only of incidental interest in a study of distribution.

The distribution of fresh-water fishes ordinarily gives the best clue to the origins of species and the geological history of the areas observed, but this is not true of the greater part of the tropical Pacific. True fresh-water fishes occur in but a small part of the tropical Pacific, so that they need be considered but briefly and most of our attention will be bestowed upon the shore fishes.

By true fresh-water fishes is meant fishes belonging to families no members of which live in salt water. Many fishes living in interior rivers and lakes go down to the sea to spawn, or belong to families many members of which live in the ocean. In the tropics we also find many marine fishes entering rivers and lakes, often far in the interior, and often living there for months or years. We cannot consider these recent immigrants to be true fresh-water fishes. In the tropical Pacific true fresh-water fishes are rare over most of its extent, and occur only in the western portion.

The chief family of fresh-water fishes, and by far the largest family of all fishes, is that of the Cyprinidae. The chief center of this family is southeastern China, and India, the Malay Peninsula, Sumatra, and Borneo abound in Cyprinid genera and species. However, they extend no farther into the Pacific than to Wallace's Line, which marks the limits of those islands which once formed part of the mainland, or were connected to it. This means that to the north and east Cyprinidae have not gone beyond Mindanao and the islands of the Palawan group, since those beyond have never been united to Borneo. Wallace's Line follows the deep water between Borneo and Celebes and between Bali and Lombok, so that Cyprinidae are confined to the islands west of it. Other fresh-water fishes in the Malay Archipelago, such as the Bettas and guramis, follow the same laws of distribution as the Cyprinidae. Most of the members of the Ophicephalidae are likewise restricted to those islands which have once been part of the mainland.

There are, however, two very widespread labyrinth fishes that are of no value in a study of distribution, since they have been carried far and wide by man. These are *Ophicephalus striatus*, the "haruan" of Malaya and "dalag" of the Philippines, and the celebrated climbing perch. Their occurrence eastward of Wallace's Line, in Celebes, Halmahera, and the Moluccas is therefore worthless in distributional studies.

In the fresh waters of New Guinea, and the adjacent Aru Islands and Waigiu, are representatives of the Melanotaenidae, an Australian family of fishes. Their presence here dates from the time when these places were part of the Australian continent.

Scattered throughout the Polynesian islands, wherever fresh-water streams occur, are numerous other fresh-water fishes, some of them never found except in fresh-water streams. At the same time, it must be recognized that they are all members of marine families of fishes, or else some of the members of the family are marine. The fresh-water eels that are so abundant in species and individuals throughout the western and central Pacific, and that play so noticeable a part in folklore from Luzon to Tahiti, are, after all, marine fishes that enter fresh water in early life and remain there until mature. Wherever there are permanent fresh-water streams in the islands of Melanesia, Micronesia, and Polynesia we find fresh-water fishes, belonging chiefly to the families Kuhliidae, Gobiidae, Eleotridae, Syngnathidae, Megalopidae, and Zenarchopterus. Many of them are only found in fresh water, but they belong to families living for the most part in the sea. Unquestionably the young can survive salt water, so that they have reached all islands with permanent streams and established themselves there. Since Cyprinidae could not reach the major part of the Philippine Archipelago, it is easy to see why small gobies have occupied the streams and lakes and developed genera and species for every river system and lake drainage. The gobies of Luzon and the Visayas therefore take the biological position assumed by the carp family in China and the eastern half of the United States. It can readily be seen that the gobies, pipefishes, kuhliids, and others are of no value in studying the origins of the Pacific islands, although they are very useful in studying the lines followed in distribution and the methods by which they were dispersed.

The abyssal fishes are, as is well known, nearly all of very wide distribution, being at home in the Atlantic as well as the Pacific and Indian oceans, and are therefore not to be considered at this time. Most of the large pelagic fishes of the Pacific likewise occur in the Atlantic, and some of them roam all seas except those of the far north and far south. Whether they are swift and powerful swimmers, capable of continued high speed, or huge sluggish fishes that subsist on macroplankton, they occur alike in both hemispheres and are equally at home in all waters that are not too cold. About 65 species of pelagic fishes, most of them large and some of them among the most gigantic of all fishes, occur in the tropical Pacific and also in the Indian and Atlantic oceans. Most, if not all, of them evidently originated in the East Indies and gradually dispersed over the Pacific and Indian oceans. These include at least 10 species of sharks, belonging to 8 genera and at least 5 families, and 2 rays representing 2 distinct families. The bony fishes are represented by the following: Elopidae, 1 species; Albulidae, 1 species; Synodontidae, 1 species; Belonidae, 1 species; Hemiramphidae, 3 species; Exocoetidae, at least 9 species; Lampridae, 1 species; Mugildae, 1 species; Synodontidae, 1 species; Thunnidae, at least 7 species, Xiphiidae, 1 species; Gempylidae, 3 species; Coryphaenidae, 2 species; Nomeidae, 2 species; Carangidae, apparently 4 species; Rachycentridae, 1 species; Priacanthidae, 2 species; Lutianidae, 1 species; Lobotidae, 1 species; Gobiidae, 1 species; Echeneidae, 2 species, Balistidae, 1 species;

Monacanthidae, 2 species; Tetraodontidae, 1 species; Diodontidae, 2 species; Molidae, certainly 2 and probably 3 species; Antennariidae, 1 species.

The manner in which these fishes have reached the tropical Atlantic has been well and plausibly elaborated by Dr. E. W. Gudger in his articles on the geographical distribution of the whale shark and on the natural history and geographical distribution of the pointed-tailed ocean sunfish. We may safely assume that most, if not all, of the pelagic fishes listed above have reached the Atlantic Ocean in the same way.

There remain to consider the shore fishes of the tropical Pacific, a vast assemblage of species distributed over hundreds of genera and very many families. They belong, for the most part, to the East Indian fauna, richest of all in the number and variety of species contained. In the island world between the mainland of Asia and New Guinea is a welter of reefs, islands, seas, and bays, with a vast diversity of conditions that has developed the greatest of all fish faunas. From this center of development fishes have spread to greater or lesser distances over the tropical portions of the Pacific and Indian oceans. A great many have extended their range northward beyond the tropics, to the southern coast of China, the Riu Kiu Islands, and southern Japan. A very great number range eastward into Melanesia, while a smaller number are found in Micronesia and Polynesia, and some have even established themselves in the Galápagos, at Panama, and in the islands off Central America and Mexico. In the other direction, a very large number have been carried westward across the Indian Ocean to the Red Sea and Zanzibar, while a considerable number have traveled as far south as the coast of Natal, South Africa.

The exact manner of the distribution of so many fishes over such vast areas is not always clear, and neither are the causes evident that make some fishes of very local distribution while others apparently but little different are very widely scattered. The primary reason for the very great range of many East Indian fishes over the tropical Pacific and Indian oceans is, of course, the strategic position of the East Indies with reference to the great ocean currents of Indo-Pacific waters. This primary cause is modified by many other factors, most of which are vaguely or not at all known. There are two very grave obstacles to an adequate knowledge of the distribution of fishes in the tropical Pacific at the present time. One is the lack of intensive collecting at a sufficient number of places in this enormous area which is many times the area of Europe. In Polynesia only at the Hawaiian Islands do we have a really adequate picture of the local fish fauna. Elsewhere our knowledge is more or less fragmentary, even though the total number already known from a given group is about as great as that known from the Hawaiian group. This is conclusively shown by the fact that every time anyone does any real collecting at any group of Polynesian, Melanesian, or Micronesian islands he obtains species not hitherto reported from that particular region, and usually finds some new species also. Even in the Malay Archipelago, the center of fish life, the fauna is very, very far from being adequately known. Every time intensive collecting is done anywhere in the East Indies, including the Philippines, large additions are made. They may be new species, or kinds not hitherto known from the region, but it is very evident that exploratory work is far from being completed and that it will be needed all over the tropical Pacific for a long time to come.

The second obstacle is our imperfect knowledge of the ocean currents of the tropical Pacific. We have not only the trade-wind belts both north and south of the equator, and the belt of calms between them, just as in the far smaller and simpler tropical Atlantic region, but also another set of winds quite unknown in the Atlantic. I refer of course to the monsoons, those periodic winds which so profoundly affect the Philippines, the Sunda Islands, and in fact all the great islands and land masses appended to southeastern Asia.

As a result of the trade winds, we find in the tropical Pacific, just as in the Atlantic, a north equatorial current and a south equatorial current, both flowing westward, and between them a shifting equatorial return current flowing eastward. This, however, is only in the central and eastern Pacific. When the East Indies proper are reached, west of New Guinea, these currents break up into a criss-cross medley of bewildering complexity and variability. This is in part due to the vast number of intricate channels, seas, and shoals of varying depths, and in part due to the fact that the trade winds disappear and are replaced by the monsoon winds. These are seasonal winds that blow for about 5 months from northeast to southwest and, after an interval of changeable winds, blow for about 5 months in the opposite direction, from southwest to northeast. This of course produces a complex of variable currents, variable in rate of movement and variable in direction. From the region southeast of the Philippines arises the Kuro Siwo or Japan current, which flows northward along the east coast of the Philippines. Both the north and the south equatorial currents give off branches which ramify throughout Melanesia, Polynesia, and Micronesia, most of Polynesia being within the influence of the south equatorial current. The Hawaiian Islands, most isolated of the Polynesian island groups, are not directly reached by the main oceanic currents, and their fish fauna has fewer East Indian species than those of the other tropical Pacific islands. A branch of the north equatorial current passes some of the reefs and small islands south of Hawaii, and in that way they are indirectly reached by the East Indian fishes.

In the great mediterraneans of the Malay Islands, the Sulu Sea, the Sea of Celebes, and the Banda Sea, there have undoubtedly arisen many hundreds of species, most of which have become distributed very generally throughout the Malay Archipelago and beyond. From one reef and shoal and island to another, fishes have made their way, until very many have reached North Australia and the Fiji Islands, a smaller number Tahiti, and still fewer the Marquesas Islands. The Kuro Siwo has carried them northward to the Riu Kiu Islands. Even remote dots like Marcus Island have a typical East Indian fish fauna. Of course, as one gets farther away from the great center of fish life there is a rise in endemism, and the East Indian element becomes less dominant. However, the endemism is sometimes more apparent than real, and more intensive collecting over a greater range would show many of the localized endemics to be really widespread and perhaps East Indian after all.

To show how little we actually know of the details of fish distribution in the Pacific, let me cite some striking examples of little known but widely scattered fishes which I have personally secured.

Cingulogobius naraharae, from Okinawa, Riu Kiu Islands, is a very small banded goby which I took also in the Marquesas Islands, most remote of the Polynesian groups.

Uropterygius supraforatus, a small moray known from one Samoan and 3 Tahitian specimens, was found in the stomach of a sea snake, taken on a reef near Marinduque, in the central Philippines.

A peculiar snake-eel, *Achirophichthys kampeni,* was discovered in a stream near the sea at Humboldt Bay, New Guinea. A dozen years later I found it in a mountain brook in northeastern Luzon, about 75 miles from the sea, and 7 years after that in the Papenoo River, Tahiti.

Coelonotus argulus, a pipefish long known from Comoro and Madagascar, off the African coast, was later found at Flores, in the East Indies, and finally taken by me in the Marquesas.

Ptereleotris evides, a free-swimming eleotrid, was described from 2 examples taken at Wakanoura, Japan, and was not further known until I caught 3 specimens in the New Hebrides.

Gnatholepis gemmeus, a small goby known only from the Philippines and the New Hebrides.

Ctenogobius decoratus, a Philippine goby later taken in Fiji and recently in Singapore.

Ctenogobius suluensis, a goby from the Sulu Islands, and *Amblygobius insignis*, another Philippine goby, both secured in the Solomon Islands.

Cryptocentrus leucostictus, a goby described from Tonga and later taken by me in Fiji and the central Philippines.

Synchiropus splendidus, a most extraordinary callionymimid which I took in the Sulu Islands, and which later was turned up from the Great Barrier Reef, Australia.

Parapercis schauinslandi and *Iniistius niger,* both only known from the Hawaiian Islands and considered endemic there, were taken by me in the Philippines.

Many more examples could be cited. Intensive collecting in the Philippines has revealed the presence of many fishes supposed to be found only in Java, the Moluccas, Fiji, Hawaii, or other faraway localities. Likewise, during the past few years reef and shore collecting at Singapore has shown that many species only known from the Philippines are really common in the reefs of the South China Sea and about Malaya.

The Marquesas, most remote of all the island groups, lie far to the east, and the Hawaiian Islands, most widely separated from other groups, and farthest removed from the main ocean currents, are away to the northeast. Between them and the American mainland lies a tremendous waste of water, devoid of islands and reefs. It is 3000 miles of deep open sea from the Marquesas to the Galápagos Islands, 600 miles off the Ecuadorean shore. From the Hawaiian Islands to the Revilla Gigedos, off the Mexican coast, is equally far, if not farther. The fish fauna of the Marquesas is markedly East Indian, as a list of its species shows. But no ocean current flows from the Marquesas to the Galápagos, or Panama, or from Hawaii to Mexico or Central America. As Ekman has pointed out, this vast expanse of deep water is the greatest barrier to the distribution of tropical sea life, and causes the greatest break between the Indo-Pacific fishes and those of tropical America.

Yet, strange as it may seem, a number of East Indian fishes are found about the Galápagos Islands, and lesser numbers are known from Cocos Island, Panama, and the islands of tropical Mexico.

To explain satisfactorily all the cited illustrations of irregular distribution, and the presence of East Indian fishes off the Mexican coast, would need a far more adequate knowledge of ocean currents in the Pacific than we now have. Conversely, it is evident that if we had a complete knowledge of the distribution of fishes in the tropical Pacific we could plot all the important ocean currents with reasonable accuracy.

The only current with which it would seem possible for the East Indian fishes to reach the American coast is the equatorial countercurrent, along which they would have to travel at least a thousand miles farther than the distances already cited. Such fishes as the porcupine fishes, for example, simply let themselves drift in currents and are carried incredible distances; the young are taken now and then in mid-ocean, a thousand miles from the nearest land. Pipefishes, puffers, other feeble swimmers, and the young of many species are carried far and wide by ocean currents. Many are eaten by birds and other fishes, and many are lost at sea, destroyed by storms, or carried to unfavorable places. Most of this distribution has taken place very slowly, in part by currents as stated, and in part when a given species has made its way into the Pacific from island to island and reef to reef. The western and central parts of the Pacific are sprinkled with thousands of isles and reefs. Very many of the latter do not come to the surface but are near enough to it to afford food and shelter to many forms of life. From one to another of such reefs fishes have made their way until many kinds have populated every favorable locality throughout Polynesia. A few kinds, perhaps several dozen in all, have crossed the vast expanse of deep open water in the eastern Pacific and reached the Galápagos and other islands off the Americas, and the mainland itself.

Such a remote tiny isle as Marcus Island has a purely East Indian fish fauna, evidently brought by some branch of the Kuro Siwo. Much illumination would be shed on the Hawaiian problem if a great deal of intensive collecting should be done in the Marshall Islands. It is possible that this would show a significant percentage of supposedly endemic Hawaiian species.

THE RELATION OF THE MARINE FAUNA OF HAWAII TO THAT OF OTHER SECTIONS OF THE PACIFIC AREA

By C. H. Edmondson

In this discussion I will attempt to present some considerations on the position which Hawaii holds with respect to certain groups of marine fauna. But a small number of these data represent my own personal contribution, as it is necessary to bring to the front the observations of numerous investigators who have not only accumulated data but have also attempted to analyze them, and have even ventured to suggest solutions for some of the riddles of biological distribution in the Pacific Ocean.

A general knowledge of the marine fauna of the central Pacific had its inception in the Polynesian peoples themselves. A courageous maritime race depending for their livelihood, in large part, upon the sea, through necessity learned much about the ways of the ocean population.

The modern scientific conception of this fauna developed, however, as the results of the efforts of a long list of officially organized groups and private collectors, each adding something to the growing sum of information.

Beginning more than one hundred and fifty years ago and extending through parts of three centuries, a series of notable explorers and investigators have included the central Pacific area in their itineraries. Among these may be mentioned Captain Cook and his staff of scientists, near the end of the 18th century; Freycenet, in 1825; Captain Beechey of the *Blossom,* 1825–26; the United States Exploring Expedition, 1838–42; the *Challenger,* 1873–76, and the *Albatross,* which during the spring and summer of 1902 investigated the deep waters about Hawaii and greatly stimulated interest in the marine fauna of that archipelago. It is an obvious fact that we began investigations of the marine fauna of the Pacific on the bottom and worked up. At the turn of the present century much more was known about deep-sea forms of life than about those of the shores and reefs, at least about the Hawaiian Archipelago.

During the past twenty years, biological knowledge of both land and sea has been greatly broadened in the central Pacific area. The *Tanager* and *Whippoorwill* expeditions surveyed the leeward islands of the Hawaiian Archipelago, Johnston Island, the Line Islands, and Wake Island. The recent *Islander* Expedition to southeastern Polynesia carried explorations as far as Pitcairn and Rapa islands. Here and there single or small groups of investigators are collecting data which may be of use in the task of assembling the parts of the biological puzzle of the Pacific.

Activity in this direction has been no less in other Pacific areas. From the eastern shores of this great ocean, especially from Canada and the United States, from its western fringes and from its southern boundaries has come a constant stream of contributions. Taxonomists, biogeographers, oceanographers, and many others have a part in this constructive work of filling in the details of the biodistributional picture of this area. But the horizons are extensive and, with due credit for what has already been accomplished, much more remains to be done.

Our present knowledge of the marine fauna of Hawaii is still, in many respects, incomplete, as the following index will indicate, although it represents, without doubt, parallel situations in almost every section of the Pacific. Regarding the status of the present information about the chief groups of marine fauna in Hawaii, the following may be stated. Among the lower forms, the Foraminifera, which have considerable distributional significance, have remained almost untouched, especially those of the reefs and shoal waters. Cushman has determined the small collection taken by the *Tanager* Expedition, and the deep-water species from the *Albatross* have been listed, but no serious systematic study has been made of the near-shore forms. This remains a rich field for investigation.

The apparently large sponge fauna of Hawaii is even less well known than are the Foraminifera. The lack of interest which most zoölogists exhibit for the Porifera and the few specialists working in this group are responsible for this taxonomic gap. The coelenterate fauna of Hawaii is fairly well known. Investigations of Vaughan, Mayer, Nutting, Verrill, and others have made this possible. Certain sections of this large phylum need more attention. Little work has been done on shoal-water hydroids in the islands. Recent attention given to fouling organisms in Hawaii indicates that a much larger shallow-water hydroid fauna is present about the islands than was formerly believed.

Largely by the works of Fisher and Clarke, and Agassiz and Clarke, the Hawaiian echinoderm fauna has been made known. This group, however, is still of great interest to the taxonomist in Hawaii, as new forms and forms previously unknown to that region are frequently appearing.

The composite group of marine worms in Hawaii has been incompletely studied. Treadwell's papers have treated collections of polychaetes taken by the *Albatross* and *Tanager,* but a large population of reef dwellers still remains to be investigated.

The large molluscan phylum of Hawaii has received and is still receiving taxonomic attention. A recent manual by Dall, Bartsch, and Rehder on the pelecypod mollusks of Hawaii is the most nearly complete treatment of the group in this region. The same authors are monographing the gasteropods of Hawaii as a counterpart of the manual already published.

Among the crustacean fauna of Hawaii, the Brachyura and the Macrura are fairly well known. Some groups of the phylum need revision and some, as for example the amphipods, isopods, and copepods, have not yet received the attention deserved.

With this hasty survey of the Hawaiian marine fauna, known as completely as it is with respect to some groups and as meagerly as it is with respect to others, we may well inquire what biologic relationship exists between this most isolated archipelago and other regions of the Pacific area, far or near.

In forming such comparisons certain groups of organisms may rightly be excluded. Free-swimming forms, pelagic in habitat, often range the waters of many seas. Likewise, abyssal forms tend to become cosmopolitan. Certain sedentary forms are also world-wide in distribution, at least within certain latitudinal boundaries. Some of these have easy means of transportation. *Bugula neritina* is an example. To microscopic slides suspended in the sea during a single night, myriads of larvae of *Bugula* often become attached, and young colonies from 1 to 2 mm. in height are developed between 6 P.M. and 6 A.M. In 14 days the colonies are 25 mm. high and discharging larvae. A ship anchored overnight in Hawaiian waters may collect large numbers of this species. In two weeks' time the ship may be in Kobe, Manila, Sydney, or Panama, and larvae of Bugula are spread far and wide. Barnacles, serpulid worms, and some other organisms may be widely dispersed in like manner.

Intertidal inhabitants, however, and those with restricted local range in the adult stage, and other forms, sedentary or not, having no ready means of moving from place to place while adult, are especially significant in distributional comparisons.

Among the coelenterates the corals are well adapted for distributional studies. These sedentary forms, with small likelihood that adult colonies of them will be transported for any considerable distance by natural means, doubtless have depended upon free-swimming planulae for their dispersal.

The corals of Hawaii present some interesting problems in distribution. Vaughan, to whom credit is due for a very comprehensive monograph of Hawaiian species, was so impressed by their similarity with those of the South Pacific and East Indian regions that he ventured to suggest that Hawaii must have received her coral immigration from the southwest in comparatively recent times. There are indications, however, that this migration from south to north was not over a direct course. The trend of ocean currents would, unless they have shifted in the course of time, preclude this. But within the fauna itself are certain peculiarities which would point toward an infiltration by way of a western Pacific route. Species of the genus *Acropora* are exceptionally well developed to the south and west of Hawaii, and until a few years ago it was believed that this genus was unrepresented in the Hawaiian Archipelago. Now it is known to occur on some of the reefs among the leeward islands, but apparently has not reached the islands toward the southeast extremity of the chain. It is also well known that a number of well-developed families of corals, well developed in the South Pacific, are entirely absent from Hawaii, and others are represented by one or very few species.

Dana's explanation for the decadent condition and peculiarities of the Hawaiian coral fauna was that the archipelago lies on the outer fringe of the coral reef area and is unfavorable so far as temperature is concerned. Vaughan suggests that the inability of the planulae of certain species to survive over long distances may account for the character of the Hawaiian coral population.

Free-swimming planulae of corals have persisted in my laboratory for sixty days without becoming affixed. If caught in a current moving at the rate of two miles per hour, the organisms might have traveled approximately 2500 miles in sixty days. How much longer than sixty days coral planulae may remain in a free-swimming state, under certain conditions, I do not know. In comparative studies of the responses of coral planulae to various physical and chemical factors I have found (unpublished data) significant differences among species. I would make a plea for more complete investigations of larva forms of all kinds of organisms, of their ecology, and of their behavior under normal and abnormal conditions. In such studies I believe we may find important clues to the extended or restricted dispersal of at least some groups of marine animals.

Vaughan sees no evidence of coral migration between tropical America and Hawaii, although a few species and more genera are common to the two regions. The similarity of the coral population of the west coast of Panama to that of the South Pacific probably calls for a wave of migration from the East Indian area northeast through Polynesia, with some elements reaching tropical America, while another wave from a similar source probably spread northward through the western Pacific, populating the warmer waters of Japan and Micronesia and eventually reached Hawaii, probably the leeward islands first.

Of other coelenterate groups of Hawaii, the sea anemones have close affinities in the South Pacific and East Indian areas. Pelagic medusae, few in number and fewer endemic, are for the most part widely distributed forms. Some peculiar elements, like the walking medusae and stalked jellyfishes, have become a part of our shoal-water fauna. These unique forms have relationship with species in distant parts of the world. The walking medusae, endemic in Hawaii, have affinities with species of the extreme South Pacific area and with European waters; the stalked jellyfish, a scyphozoan, also endemic, is closely allied to a Japanese species. Their ecological association with shoal-water algae may explain the means by which they have been able to cover great distances.

It is also suggested that more complete investigations would reveal the forms in intervening areas.

H. L. Clarke and W. K. Fisher, who have contributed greatly to our knowledge of Hawaiian echinoderms, are in agreement that this group in Hawaii shows closer relationship with that of the East Indies and the Indian Ocean than with any other area. They consider it an attenuated Indo-Pacific fauna present in Hawaii long enough to have added to itself certain endemic forms. Clarke is of the opinion that the sea urchins found their way from the southwest by way of the Caroline and Marshall islands. Wake Island, which is close to the Carolines, is decidedly more Indo-Pacific than is Hawaii. Palmyra, about 1000 miles south of Hawaii, is also Indo-Pacific with respect to its echinoderm fauna but differs somewhat from Hawaii and, according to Clarke, probably received its immigration by way of the Gilbert, Ellice, and Phoenix islands. Johnson Island, about 700 miles southwest of Hawaii, is essentially Hawaiian with respect to both its echinoderm and crustacean faunas.

In discussing the probable origin of the starfish fauna of Hawaii, which comprises about 60 species, most of which are beyond the reef zone, Fisher sees two possible sources. By far the larger group includes forms ranging from the Red Sea, through the Indian Ocean, to Australia, China, Japan, and Hawaii. Another and very small group is believed to have reached Hawaii from tropical America. Five species have been recorded as coming from this direction, only one of which has, however, been verified.

Recent investigations about the offshore islands of the eastern fringe of the Pacific, however, indicate a greater affinity with Polynesian biology than was once believed to exist. Such forms as *Tripneustes gratilla, Echinometra oblonga, Brissus latecarinatus, Metalia spatagus,* and *Mithrodia bradleyi* in the eastern Pacific tropical and subtropical waters are familiar shoal-water species in Hawaii. If *Echinometra oblonga* is identical, except for color, with *Echinometra mathaei,* as some believe, then at least one sea urchin has spanned the breadth of the Pacific Ocean. This species is probably the most widely distributed of the echinoderms.

A very decided Japanese element is seen in the Hawaiian echinoderm fauna. Some of these species have been reported in Hawaii only recently, although it is not certain that they are recent immigrants. *Holothuria edulis,* a typical Japanese species, was first observed in Hawaii but a few years ago. *Coscinasterias acutispina,* a Japanese starfish, has been established on Oahu and on Maui, apparently for a long time. More than 20 species of Hawaiian echinoderms are found in Japanese waters.

Some puzzling questions of distribution among the echinoderms arise. While we assume that free-swimming larvae may be an important factor in the wide dispersal of marine invertebrates, when we find a form ranging over vast expanses of the seas but possessing no free-swimming larvae it flattens out some of our theories. *Amphipholis squamata,* one of the very small brittle stars, is found from the Suez Canal to Hawaii, apparently being fairly well distributed throughout its range. It is a viviparous species without free larvae. In Hawaii we have discovered one species of *Conus* which has no free-swimming larvae. On breaking from the egg cases the larvae immediately fall to the bottom, as the shells they bear are too heavy to permit the organisms to swim. They can only creep about on the bottom.

The literature on Hawaiian marine mollusks is voluminous and greatly scattered. From numerous check lists, however, it seems clear that a large number of Hawaiian species, especially gasteropods, have a wide distribution through the South Pacific, East Indian, and Indian Ocean areas. There appears to be little doubt that this great section of Hawaiian fauna had its source to the south and west, and that its migrations paralleled those of other marine groups. Comparisons with lists of Japanese marine mollusks indicate that a considerable element has entered Hawaii from that western area. More than twenty species, mostly gasteropods, are common to Hawaiian and Japanese waters.

The degree of influence of Polynesian mollusks seen in tropical American waters has been discussed by others. A recent paper by Hertlein[1] greatly extends the range of some well-known marine mollusks. He lists 29 species found in tropical or subtropical American waters, identical with or very close to East Indian and Polynesian forms. At least ten of these are common shoal-water species of Hawaii and at least two of them span the Pacific Ocean from Japan through Polynesia to tropical America.

Not all Hawaiian mollusks, apparently, are as widely distributed as some of the common gasteropods. A monograph of the recent and fossil pelecypod mollusks of Hawaii appeared last year[2] in which the authors—Dall, Bartsch and Rehder—point out that with few exceptions the pelecypod mollusks of Hawaii, nearly 200 species, differ specifically or subspecifically from that to the south and west. Their opinion is that the immigration of the group (pelecypods) to the islands was of comparatively recent date, the fossils in the raised reefs being, they believe, of the late Tertiary, Pliocene or Pleistocene.

The shoal-water crustacean fauna of Hawaii seems to be chiefly of Indo-Pacific origin. Many of the common shore species range all the way from the Red Sea to Hawaii. One of the best references for the student of marine crustacea in Hawaii is Major Alcock's series of descriptive reports on the crustacea of the Indian seas. Another important reference is *Fauna Japonica,* which indicates the common elements not only of crustaceans but of other groups as well in the far western and central Pacific areas. Also, more complete knowledge of the crustaceans of the western shores of tropical and subtropical America have revealed a considerable Polynesian influence in those areas. In the *Proceedings* of the Second Pacific Science Congress are listed between 20 and 30 species of shore crustaceans of Hawaii also found in Australian waters, and there are probably more, in addition to many genera, common to the two localities. Among groups of invertebrates shoal-water crustaceans have apparently found very accessible means of transportation. As a whole they are a well-distributed group. Schmitt has pointed out that 9 per cent of the 181 species of crustaceans he lists from the coast of California are also reported from Japan and Kamchatka, and that 2 per cent are known from Japan, the California coast, and Atlantic littoral regions.

Certain shoal-water crustaceans show remarkable advantageous adaptations which are linked with their dispersal. Members of the genus *Trapezia* are to be found wherever pocilloporan corals are, whether it be in the Red Sea or tropical American waters. Likewise, the gall-forming *Hapalocarcinus* follows its several hosts throughout their range. Schmitt recently reported it from the west American coast.

Among the crustacean shore fauna of Hawaii we find more than 20 Japanese species and a lesser number, perhaps more than a dozen, common with the west American coasts. These are Indo-Pacific forms, one of them a widely distributed pelagic species. Miss Rathbun sees but little evidence of crustacean migration between America and Hawaii.

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[1] *Proc. Am. Philos. Soc.,* Vol. 78, No. 2, 1937.

[2] *Bernice P. Bishop Museum Bull. 153,* December, 1938.

Although the source of the shoal-water crustacean fauna of Hawaii seems clearly that of the Indo-Pacific area, it is unwise, I believe, to hazard an assertion concerning the manner in which the migration arrived. Information about the fauna in the South Pacific, added to that obtained by the survey of the *Tanager* and *Whippoorwill* of the leeward Hawaiian chain, the Line Islands, and Wake Island, indicates a series of stepping stones from the south to the north, the Hawaiian Archipelago being the last foothold for shore fauna. The South Pacific influence is still strong in the Line Islands and Wake Island, but here there is also a very decided merging into Hawaiian fauna. Johnston Island, about 700 miles southwest of Hawaii, has lost all but about 10 per cent of the South Pacific influence. Here fully 90 per cent of the shoal-water crustaceans are Hawaiian. Wake Island, far to the west, although north of Johnston Island in latitude, has lost less of the South Pacific influence. About 75 per cent of the shoal-water crustacean fauna of Wake Island are recorded from Hawaii. The *Tanager* Expedition revealed that a number of species distributed throughout the Hawaiian Archipelago are much more abundant toward the extreme northwest of the leeward chain than about the larger islands to the southeast. Some of these species are common to Wake Island and the South Pacific.

Although the evidence is meager, there is a suggestion that the Hawaiian Archipelago may have received its shoal-water crustacean fauna through the leeward islands first, the migrations coming from the south through the western Pacific area.

In summing up the data at hand relative to the dispersal of the invertebrate fauna of the Pacific Ocean, I believe there is suggested the appearance of three broad streams of migration, with more or less fusion and mergence. From the bottleneck of the East Indian area the near-shore fauna seems to have spread, in one stream, to the northeast, reaching the shores of China and Japan. Another current of migration seems to have passed northeastward through the western Pacific, reaching the Caroline and Marshall islands, Wake, and possibly the leeward chain of the Hawaiian Archipelago. A third migration probably swept through southern Polynesia to the eastward, some elements of this current eventually reaching tropical America.

RESULTS OF CORAL STUDIES AT THE PALAO TROPICAL BIOLOGICAL STATION

By SHINKISHI HATAI

THE BIOLOGY of the reef-building corals is one of the research projects at the Palao Tropical Biological Station and several investigators are engaged in the study of various aspects of this subject. I will first present a brief statement concerning this newly established biological station in the tropical islands under Japanese mandate, and then some of the results obtained by the several investigators at the station in relation to submarine illumination, silt content and zoöplankton in relation to growth of corals, liberation periods of the planula, and biochemical studies on corals.

The Palao Tropical Biological Station.—Ever since certain South Sea islands became Japanese mandated territory, Japanese biologists have desired to see a biological station established on one of them for the study of tropical fauna and flora. This desire has fortunately been realized through the financial support of the Japan Society for the Promotion of Scientific Research; the Palao Biological Station was finally established, in 1934, on Korror Island, which is near the main island of Palao.

Palao (Pelau, Palau, or Pelew) Island is situated 7 degrees north of the equator, or about 500 miles north of New Guinea and a like distance east of Davao, Philippine Islands.

The temperature ranges between 27° and 29° C. throughout the year, seldom rising above 30° C. even at the hottest time of day. The frequent squalls or sudden violent showers are not only refreshing; they form a source of drinking water—much more than is needed. The average rainfall is nearly three times that in Japan Proper.

The temperature of the sea water is constant throughout the year, ranging between 28° and 31° C. according to the region examined, the average being about 29° C. The difference between day and night temperatures is about 1°.

Korror (or Goreor) Island, where the station is situated and where the governor of the mandated islands resides, is a small island of 8 sq. km. area. The southern side of the island is deeply indented, and, with Ulupsagel Island lying just opposite to it, forms a large, circular bay, the area of which is 8 sq. km. This bay, which is now called Iwayama Bay, is connected with the outer ocean by a channel which opens to both east and west. Within the bay more than forty small islets are found. Iwayama Bay thus shows a varied degree of growth of coral reefs around each of the islands, influenced apparently by current, light, depth, etc.

This luxuriant coral growth, together with the varied degrees in the growth of coral on the different reefs in this bay, was one of the reasons why this island was chosen as the site for the proposed tropical biological station.

The station consists of a single small frame building, in which are one large laboratory room and two additional very small rooms. The laboratory is well supplied with both fresh and salt water and is provided with several boats.

Within the past three years, eighteen investigators have gone to the station. Several of them have returned, having completed their research work; others are still carrying on their investigations. The results are published in the *Palao Tropical Biological Station Studies.* I regret that I cannot present more than a mere fraction of what the investigators have obtained, and that I shall be obliged to omit any reference to the literatures. I must be content if my presentation gives some idea of what kinds of investigation are being undertaken at the station on the tropical island.

THE RESULTS OF INVESTIGATION

Abe, Eguchi, and Hiro have made a thorough, systematic survey of the bay and have divided the sea area into sixteen regions, in accordance with the characteristic faunal association and coral distribution. Corals have been collected from each of the regions, and species names determined and their distribution studied from the ecological standpoint. So far, Eguchi has been able to determine 146 species belonging to 43 genera. More species may appear in future surveys. Practically all the specimens found in Iwayama Bay consisted of species, already known from elsewhere, which show geographically wide distribution in the tropical seas. Only the following four species were new: *Porites iwayamaensis, Pavona garambiensis, Lobophylia* (*Palaophilia*) *hataii,* and *Favia palawensis.*

Hydrographical conditions.—Matsuya has shown that the average sea water of the bay differs from the water of the outer sea in its higher temperature, lower salinity, lower oxygen content, lower pH value, lower concentration of excess base, higher silicate content, and lower phosphate content. Moreover, slight seasonal and vertical variations have been found notwithstanding the short period of observation. The conditions are much influenced by the tides, the effect being greater in the entrance of the bay than in its inner part.

There are marked diurnal changes in hydrographical conditions in the bay, and these changes show to some degree the same tendency at the selected few positions (pool, anchorage, and passage). The changes in temperature and oxygen content usually show rises in the daytime and falls at night. Moreover, salinity, oxygen content, pH value, and excess base rise, and temperature falls, at flood tide, and show the contrary changes at ebb tide.

Submarine illumination.—Kawaguchi has noticed that in shaded or deep waters the reef corals become thin and slender, and that on the light side there are more polyps than on the dark side. This is another example which indicates an intimate relation between the amount of submarine illumination and the flowering of corals.

Motoda has carried on a careful determination of the submarine illumination at several localities in the bay, using the photochemical method of Pearsall and Hewitt (1933) ; that is, a solution of 2-per cent potassium iodide and 1.5-per cent sulphuric acid were mixed in equal volume and poured into bottles of about 50 cc. capacity, and the estimation for free iodine liberated by decomposition of potassium iodid by the effect of light was made by titration of standardized N/100 sodium thiosulphate, starch being used as an indicator.

The present investigation in Iwayama Bay has been restricted to shallow water and the flowering of reef corals has been observed at a depth shallower than 10 meters. The results, however, will explain the relation between the flowering of reef corals to their environments. Motoda has stated as a general conclusion that the common reef corals can thrive vigorously in a submarine illumination of about 30–40 per cent of surface light.

Silt content.—The fact that floating silt affects the reef corals either by falling on the living polyps or by hindering the light transmitted is well known. However, the problem of how much silt in suspension should affect the living corals, or hinder growth, needs further investigation.

For measuring the volume of the fine silt in suspension, 20 liters of water were pumped from different layers (0, 5, 10, 20, and 30 meters) and transmitted to a large glass vessel. After addition of 200 cc. of formaline, the samples were allowed to settle for 24 hours, and the sediment that condensed in 100 cc. of water was transferred to a glass cylinder and again settled for 24 hours. Thus the volume of fine silt that settles was read. The readings might indicate the volume including both silt and plankton (mostly microplankton). However, for the study of coral growth the microplankton suspending in water can be considered as silt.

Motoda has arrived at the conclusion that about 7 cc. per 20 liters of suspending silt would not hinder the vigorous growth of the common reef coral at 10 meters depth.

In this connection Abe has noted that the density of the skeleton of *Fungia* is to be correlated with the amount of sediment in suspension rather than with the velocity of current or the volume of food.

Zoöplankton.—Ecologically, the availability of plankton to corals as food depends largely upon the movement of water even if the quantity of plankton in a unit area remains the same.

Matsuya has found that the plankton is very scanty in both the bay and the outer sea. During January and April, the cell numbers per liter of water varied from 145 to 13,105, with an average of 2509, and a higher abundance of plankton was generally found in the middle and lower layer of water in the bay.

According to Motoda, the water of Iwayama Bay, in which the reef corals show active growth, contains zoöplankton to the number of about 1.7–20.7 individuals per 10 liters in the layer from 10 meters to the surface in the daytime.

Abe has found (1938) that about 1530 individuals of zoöplankton per one square centimeter of a transverse section in Iwayama Bay in the days of the spring tide are carried in a day. Abe, however, made his determination only during the daytime, and therefore vertical distribution of the plankton in the nighttime is unknown.

Fortunately, Matsuya has obtained some data on the amount of zoöplankton at midnight in the pools of Iwayama Bay. He found that there was a rapid increase of the zoöplankton which appeared abundantly both in surface water and near bottom; it was about twice the number obtained in the daytime.

Yonge and Nicholls (1930) have shown that *Fungia* can digest living plankton organisms in about 3–4 hours, or in less than 12 hours in the nighttime, according to the size of the plankton. Abe found that, in general, *Fungia* can digest about 0.057 gm. of a piece of adductor muscle of a bivalve within 17 hours. He further showed that since about 1530 individuals are carried in a day per one square centimeter of a transverse section of the current in the days of the spring tide, and hence the number of zoöplankton seized by corals is far smaller than the number of zoöplankton carried by tidal current, it is to be inferred that the food supply for corals in Iwayama Bay is sufficient, though Matsuya showed a scantiness of zoöplankton in the bay.

Oxygen consumption.—In the bay, Shiro Kawaguchi has found that most sensitive animals, such as *Goniopora, Turbinaria,* and *Porites,* show very low oxygen consumption. This is probably caused by the complete retraction of the polyps into the calices, and therefore the oxygen consumption in the full expanded state would be different from these values. This consideration may be applicable more or less to almost all other specimens, but the real oxygen consumption in active state is not yet determined.

Active expanding specimens consume oxygen conspicuously, as, for example, *Goniastrea, Acropora, Montipora,* and *Fungia actiniformis.* The deep-colored specimens containing much zoöxanthellae show high oxygen consumption. In a definite species, the heavy specimen consumes less oxygen than the lighter one.

He further noted that in all the 30 species of corals examined, practically all the oxygen was used up by the end of the experiment, and that oxygen consumption does not depend on the oxygen pressure of the medium until 50 or 40 per cent of saturation is reached.

Liberation period of planula.—As for *Fungia actiniformis* var. *palauensis,* Abe observed that its breeding period occurs about the time of new moon in September and April. So the breeding period of *Fungia* resembles that of *Pocillopora bulbosa* in these months, but whether or not *Fungia* liberates the planula in the months May to August is not yet determined. Nearly 2000 planula are liberated in one period from a single parent *Fungia*. Of the other corals in Palao, Abe also observed that *Goniastrea aspera* liberated its planula on November 23 and 24, 1935 (moon's age 27 and 28 days), that is, about the time of the new moon. *Balanophyllia* sp. liberated its planula on September 13, 1935 (moon's age 15 days), at the time of the full moon.

Motoda considers that *Pocillopora damicornis cespitosa* probably emits planula throughout the year, but he did not mention whether or not there is a definite day or days in each month for liberation of planula.

Atoda is carrying on similar observations, using 12 species of common reef-building corals. So far, he has noticed with *Seriatophora* sp. that a great number of planula are liberated during the moon's age of 2–9 days, and with *Stylophora pistillata,* 22–28 days. On the other hand, *Galaxia aspera* Quelch and *Acropora* sp. showed a daily emission of large number of planula without showing any definite period. So far as the observation of Atoda goes, the majority of the corals examined appear to show an emission of greater or less numbers of planula almost every day under laboratory conditions.

I may add here from Abe that the planula of *Fungia* attaches to the bottom of a vessel in about 3 days after extrusion, and that in the stage of about 13 days the young polyp is very sensitive to sound stimulus, though such a sensitive reaction is not seen in the adult *Fungia.*

Biochemical studies on corals.—Biochemical studies on corals have been much less extensively reported than morphological and ecological studies. While some chemical data are recorded of the skeleton of corals, we are almost entirely ignorant of the chemistry of the polyp. A good knowledge of biochemical organization of the polyp is important, particularly in understanding the mechanism of skeleton formation. Hence a series of studies has been undertaken to fill the gap. The materials used for these chemical studies are polyps gathered from several thousands of *Fungia actiniformis* var. *palauensis* Döderlein.

Keizo Hosoi has isolated the glycogen for the first time from the polyp of *Fungia*. It was identified by the examination of properties and decomposition products. He believes that glycogen has the same meaning in corals as in higher animals. The content of reducing sugar was determined, but no significant amount was found. Hosoi has determined the copper content and found that the copper content of the polyp is lower than that of the oyster, but is almost of the same order as those reported by recent workers on many marine invertebrates. The skeleton was found to be remarkably poor in copper.

It is well known that iodine is very generally distributed in the animal and vegetable kingdoms. Some species of corals are said to contain considerably large quantities of iodine in the organic substance of the skeleton, "Gorgonin." But there is no report about the presence of the iodine in the protein of the polyps of corals. Hosoi was able to determine the occurrence of iodine in the polyp of *Fungia* in organic combination. The amount of iodine contained was 0.41–0.49 mg. per 100 g. of fresh matter.

Hosoi further studied the distribution of nitrogen in the protein of the polyp of *Fungia*. He arrived at the general conclusion that monoamino acid-N in the polyp of *Fungia* is a little more than in the muscle of a rabbit, but diamino acid-N in the polyp of *Fungia* is a little less than in the muscle of a rabbit.

As to the inorganic composition of the skeleton of *Fungia*, Hosoi has shown that the skeleton of *Fungia* is remarkably abundant in calcium and CO_3. Calcium and CO_3 amounts to about 90 per cent of the skeleton. Calcium and CO_3 are about 38 per cent and 52 per cent of the skeleton, respectively. Provided that calcium and CO_3 are in the combination of calcium carbonate, the amount of calcium in the skeleton is a little more than that of CO_3. Consequently the skeleton seems to contain calcium carbonate and the other calcium salts. The great amount of the inorganic constituents in the skeleton of *Fungia actiniformis* var. *palawensis* is calcium carbonate.

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OBSERVATIONS ON THE BIOLOGY OF CORAL REEFS

By C. M. Yonge

Coral reefs are usually regarded as geographical features rather than as the by-products of the activities of the members of one of the most successful of all marine communities. This is largely due to the fact that much the greater part of the very voluminous literature on this subject is essentially descriptive, geographical rather than biological in character. In this communication, based to a large extent on the work of the Great Barrier Reef Expedition, 1928–29, and on later experience of the author at the Tortugas Laboratory of the Carnegie Institution of Washington, the importance of knowledge of corals as living things, highly adapted to their environment, is emphasized. As it is impossible in short compass to dwell on all aspects of this wide-embracing subject, attention is confined to four matters of particular importance, namely, adaptability of corals, nutrition, significance of the zoöxanthellae, and the question of spawning temperature and distribution.

Adaptability of reef corals.—Biologically considered, coral reefs may be defined as marine communities found only in shallow tropical waters. The dominant organisms are Madreporaria containing zoöxanthellae (i.e., "reef-building corals") together with certain Hydrocorallinae and Alcyonacea both of which also contain zoöxanthellae. In the Atlantic, but not usually in the Pacific, Gorgonacea are also of importance. Owing to the exceptional powers of skeleton formation possessed by the majority of these organisms, massive reefs have been constructed by them and these provide surface and shelter for a varied assemblage of other animals and plants which, with the corals, constitute the marine community of the coral reef. Some of these organisms, especially Foraminifera and Mollusca among the animals and Nullipores among plants, assist in the formation and consolidation of the reefs. Other organisms, again both animal and plant, bore into coral rock and, in association with physical agencies, tend to disintegrate the reef mass.

The immense size and widespread occurrence of reefs in tropical waters is a sure indication of the outstanding success of the Madreporaria. Such success invariably implies great powers of adaptation. Examination of the constituents of a fully developed coral reef reveals a wide variety in the form of the skeleton in the various species of Madreporaria and in the size and form of the polyps. These variations are to be interpreted to a large extent in terms of adaptation of particular species of corals to particular environments on the reef they inhabit.

Corals establish themselves on shallow submarine platforms (the origin of which is not the direct concern of the biologist) and grow upwards. It is possible, as postulated originally by Wood-Jones (1912), that light is the dominant influence controlling direction of growth. Gradually the coral mass is brought within the influence of wave action. As a direct result of this the general form of the reef is molded in relation to the action of the sea. Of a fringing reef, the seaward side only is exposed to wave action, the landward surface being always in calm water. The reefs of the Great Barrier Reef of Australia are orientated in relation to the southeast trade winds. The exposed surfaces descend steeply into deep water and are composed of compactly growing coral able to withstand the full force of the sea. The protected slopes descend gradually into deep water and coral tends to grow in the form of flat-topped pinnacles of little structural stability. This asymmetry, shown diagrammatically in figure 1, was first recognized and described by Paradice (1925). During the summer months when winds of cyclonic force may blow from northerly quarters, this structurally insecure coral may be uprooted and thrown up on the lee of the reefs, giving rise to the typical "boulder zone" of "nigger heads" so characteristic of these reefs within the cyclone belt.

Finally the coral mass breaks the surface and so becomes exposed, at low tide, to the air. Hence corals, by their remarkable powers of skeleton formation, expose themselves first to wave action, thereby bringing into being a variety of environments, on their exposed faces, their upper surfaces, and their sheltered slopes, and later expose themselves to shore conditions even though, as is true of both barrier reefs and atolls, they may be far removed from any land mass.

To take a specific example, examined in detail by the Great Barrier Reef Expedition. Stephenson, Stephenson, Tandy, and Spender (1931), as a result of a study of Yonge Reef on the Outer Barrier, were able to divide the exposed surface into the following clearly defined regions: (1) outer ridge; (2) outer moat; (3) reef crest; (4) inner moat; (5) boulder zone; (6) anchorage coral zone; (7) zone of coral heads. Different genera and species of corals were found to be adapted for life within these different zones. Broadly, it may be stated that rounded solid coral colonies—for example, many Astraeids, and Maeandrines, and also some compactly growing species of *Acropora*—occur in outer regions. Encrusting corals, especially members of the Agaricidae, but also encrusting species of genera of many other families, occur on the reef crest, which is typically cemented with lithothamnion and exposed to the full rush of the surf. Branching corals, notably species of *Acropora*, *Pocillopora* and *Seriatopora*, and foliacious corals, such as species of *Echinopora* and *Montipora*, are especially abundant in the anchorage coral zone and in the zone of coral heads. Finally, on the sandy areas in the moats and between the pinnacles of the rock on the sheltered side of all coral reefs are found unattached corals, namely, fungids in the Indo-Pacific (Marshall and Orr, 1931) and *Maeandra areolata* in the Atlantic (Yonge, 1935*a*).

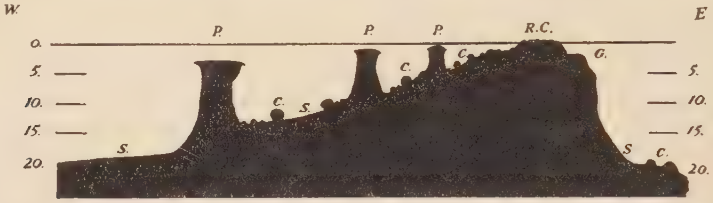

Fig. 1.—Vertical section east to west through a typical reef of the Outer Barrier. *C*, clumps of growing coral; *E*, east; *G*, shelf of growing coral; *P*, flat-topped pinnacles of coral growing from various depths on the lee; *R.C.*, cemented reef crest; *S*, sandy bottom; *W*, west; 0–20, depths in fathoms. (After Paradice.)

Corals which live in regions exposed at low tide are adapted physiologically for withstanding shore conditions involving exposure to a great range of temperature and salinity and to the danger of desiccation. Detailed ecological surveys across coral reefs, such as those of Mayer (1918*a*) at Murray Island, of Manton (1935) at Low Isles, and of Abe (1937*b*) at Palao, have revealed a regular zonation of coral species from regions of great exposure high on the shore down to low tide level. This zonation is a result of the varying degree to which corals are adapted for withstanding shore conditions, as shown by the experimental work of Mayer (1918*b*, 1924) on resistance of corals to high temperatures, of Vaughan (1919), and of Wells (1932) on resistance to variations in salinity, and of Mayer (1918*a*) and of Vaughan (1919) on resistance to the effects of desiccation.

Like all sedentary organisms, corals are exposed to great danger of suffocation from the effects of falling silt. But the importance of this factor in controlling the distribution of corals has probably been overemphasized in the past, owing to ignorance of the great efficiency of the mechanisms possessed by corals for overcoming this danger. Material is carried off the surface of the coral colonies by the action of cilia which cover the coenosteum as described in detail by Yonge (1930*a*) and by Marshall and Orr (1931). This cleansing action is naturally most highly developed in the unattached corals which live on the surface of sand. Both *Fungia* (Marshall and Orr, 1931) and *Maeandra areolata* (Yonge, 1935*a*) can uncover themselves, equally efficiently although by somewhat different means, when entirely buried beneath the sand, as they may frequently be during periods of stormy weather. Only corals found high on the shore, for instance *Coeloseris mayeri* (Yonge, 1930*a*), rely to a large extent on wave action for the cleansing of the surface of the colony from falling silt.

Adaptation in corals thus involves modifications of the form of the skeleton to resist water movements of various kinds, to deal efficiently with the problem presented by falling sediment and, finally, to succeed in these without impairing the efficiency of the polyps as feeding organs.

It has been suggested, notably by Wood-Jones (1907, 1912), that coral species are actually very few in number and that the majority of apparent species are actually growth forms, the few true species being capable of great modification to fit them for life in a variety of different habitats. Vaughan (1919) gave qualified support to this view. Stephenson and Stephenson (1933) discussed the matter in detail as a result of experiments carried out in the course of the Great Barrier Reef Expedition and came to the general conclusion that "species in the ordinarily accepted sense of the term do exist in many coral genera in considerable number, and that many of them are fairly easily recognized in the field; and that Wood-Jones has considerably overstressed the effect of environmental conditions on the corals, although such an effect certainly exists, and is responsible for a considerable range of variations." Work at the Tortugas on *Siderastrea radians* (Yonge, 1935*b*) revealed that the flattened form of this species, typical of colonies growing on beach rock exposed to the full action of the surf, gave place in the still, sediment-laden waters of the moat at Fort Jefferson to rounded colonies with larger calices possessing usually a complete fourth cycle of septa and a very well developed columella. These colonies have a much greater power of removing sediment than the flattened colonies from the surf region. They are clearly only growth forms of *S. radians* adapted for life under different environmental conditions. Abe (1937*b*) has demonstrated the important effect of water currents and wave action on coral growth and also of sediment.

In summary of the contents of this section of this communication, previously published words of the author (1935*b*) may be quoted: "The great success of the Madreporaria, which is so forcibly demonstrated by the widespread occurrence and immense size of coral reefs, may not unreasonably be attributed to the presence within the group of species highly specialized for a particular environment, and others capable of wide modification in form which enables them to adapt themselves for life in a variety of different environments. The acceptance of this view would certainly explain, and perhaps tend to allay, the conflict between those who believe in the validity of the great number of species of Madreporaria which have been described and those who regard the majority of these as no more than growth forms."

Nutrition.—It is only necessary under this heading to reëmphasize the results obtained during the course of the Great Barrier Reef Expedition (Yonge, 1930*a*, 1930*b*, 1931*a*). Species of forty genera of corals were studied and these were found, without exception, to be specialized carnivores. Abe (1938) records similar results from a study of sixteen species of corals from Palao. Corals only accepted food of animal origin and were incapable of digesting plant material even when this was actually introduced into the coelenteron. Feeding was almost exclusively by night, when alone the great majority of coral species expand. Digestion was very rapid and, as a result, the coelenteron was empty in the daytime. This explains the absence of food material in the coelentera of corals collected by day, a fact which has in the past been advanced as an argument in favor of the view that corals do not collect animal plankton but obtain nutriment from their contained zoöxanthellae. Actually no evidence was obtained that these algae provide food for the corals under any circumstances. They are indeed rapidly ejected in great numbers when corals are starved (Yonge and Nicholls, 1931*b*). Although the zoöplankton in coral reef waters is certainly sparse in comparison with that in temperate waters during the period of the spring increase, yet taken over the entire year the amounts in the two regions are very similar (Russell, 1934). It must also be borne in mind that in the warm waters of coral seas there is a very rapid replacement. Development is quick and the zoöplankton in consequence will be able to withstand the constant "grazing" of the coral polyps. The work of the Great Barrier Reef Expedition certainly gave no support to the view that the zoöplankton is insufficient to provide for the food requirements of the dense population of Madreporaria and other Coelenterata found on coral reefs. The surface of a coral colony when fully expanded at night represents an extremely efficient feeding mechanism for the capture of zoöplankton organisms, which are only present in appreciable numbers in the surface waters after nightfall. These are secured by the nematocysts and conveyed to the mouth, usually by means of tentacles but, where the tentacles are too short for this—as, for example, in most species of *Fungia, Herpetolitha,* and *Polyphyllia*, in *Tridacophylla lactua,* and in *Merulina ampliata*—as a result of the reversal of the beat of cilia which are otherwise concerned with the cleansing of the surface of the colony. No group of animals possesses so great a ratio of feeding surface to the mass of the tissues which, in the majority of the Madreporaria, represent no more than the thinnest film over the surface of the skeleton they form. The energy needs of corals are low, the rate of respiration being, in the majority of species, very much lower than the figures given by Mayer (1918*b*, 1924). Further details on this point are given below.

Significance of the zoöxanthellae.—The true significance of the relationship with zoöxanthellae which is universal amongst true reef builders is difficult to determine but is possibly of fundamental significance. The zoöxanthellae are highly specialized for life within the endoderm cells of corals and of other Coelenterata. They never occur free in the sea, being carried from generation to generation by way of the egg and planula. They possess no sexual stages, increasing by simple division and being enclosed in a relatively stout cellulose wall (Yonge and Nicholls, 1931*a*). They obtain shelter and food as a result of their life within the tissues of the corals. This food consists of carbon dioxide used in photosynthetic activities and of nitrogen and phosphorus, in the form probably of ammonia and phosphate respectively, needed for protein synthesis (Yonge and Nicholls, 1931*a*). They feed, therefore, on the waste products of metabolism from the corals, and it was experimentally determined that reef-building corals, so far from excreting phosphate into the surrounding water, will actually remove phosphate from this water owing to the demands of the algae. This occurs even when the phosphate content is increased artificially to 50 mgm. per liter. On the other hand, *Dendrophyllia,* a eupsammiid coral which, although it occurs on the surface of reefs, is actually a deep-water coral which has extended its vertical range and contains no zoöxanthellae, excretes relatively large quantities of phosphate (Yonge and Nicholls, 1931*a*). The same is true of reef builders the zoöxanthellae content of which has been artificially lowered by subjection to darkness for up to 152 days.

Zoöxanthellae are apparently always at their maximum possible abundance within any coral colony. They are limited in numbers only by light and by the quantity of available inorganic food substances needed for protein synthesis. Corals from deep water contain fewer zoöxanthellae than those from shallow water, owing to the reduced light intensity. Corals are occasionally found growing under overhanging boulders or on pier piles in deep shade, and under these conditions few algae are present. Corals kept for five months in a large light-tight box through which water was able to circulate normally lost the great proportion of their zoöxanthellae. At the end of this period the corals were very pale in color but otherwise perfectly healthy (Yonge and Nicholls, 1931*a*). Under these conditions the zoöxanthellae are ejected from the tissues by way of the "absorptive" zone at the base of the mesenterial filament. This region is excretory as well as absorptive and is the only region of the animal where particulate matter is either taken into or ejected from the tissues (Yonge, 1931*a*).

The quantity of available inorganic food material depends on the state of metabolism in the corals. The greater this is, the greater will be the production of these inorganic waste products. When metabolism is lowered by any means, as, for example, starvation, or exposure to high temperatures or to low oxygen tension (Yonge and Nicholls, 1931*a*, 1931*b*; Yonge, Yonge, and Nicholls, 1932), the zoöxanthellae are deprived of food. In consequence many die and these are ejected in the manner stated above, passing out of the mouth as brown masses embedded in mucus. Should the metabolism rise again, the former density of zoöxanthellae is gradually reattained by division of the survivors.

On the other hand, the association is *not* essential to the life of individual coral colonies. As already noted, when living in darkness they may possess few or no zoöxanthellae. The value of the zoöxanthellae to them is difficult to assess with certainty. They are specialized carnivores, and prolonged experiments in which corals were starved and fed with zoöplankton under identical conditions in both light and darkness failed to reveal that they obtained the slightest nutriment from the algae (Yonge and Nicholls, 1931*b*). On the contrary, the tissues of the starved corals began to decrease, most obviously in *Fungia,* almost as soon as starvation began, while the zoöxanthellae immediately began to be extruded in great numbers. The opinion of Boschma (1924, 1925*a*, 1925*b*, 1926) and earlier workers that corals feed on zoöxanthellae cannot be upheld.

During the light, oxygen is produced in considerable amounts by the zoöxanthellae as a result of photosynthesis. An extensive series of experiments revealed that reef-building corals exposed in sealed glass jars for 9 hours over the daytime almost invariably produced more oxygen than they consumed, although at the end of 24 hours, out of a series of corals exposed at an average depth of 4 meters, the water surrounding only one showed an increase in oxygen content (Yonge, Yonge, and Nicholls, 1932). A number of investigators have maintained that this oxygen production is of fundamental importance in the maintenance of the great volume of living matter represented by a living reef. Verwey (1931), on the basis of experiments carried out in the Bay of Batavia on *Acropora hebes,* calculated that a colony of *Acropora* weighing several kilograms would consume during a tropical night 250 cc. of oxygen for every kilogram that it weighs. A reef of some thousands of kilograms would thus consume several hundreds of liters of oxygen in one night. The water around the reefs would contain some 5 liters of oxygen per cubic meter, so that such a reef would remove all the oxygen from about 120 cubic meters of water. On this basis Verwey came to the conclusion that the oxygen produced by the zoöxanthellae during the daytime is essential for the maintenance of the corals. The validity of this claim naturally depends on the accuracy of the initial figures on the respiratory needs of corals. Mayer (1918*b*, 1924) found great differences between the relative oxygen consumption of different representative species of both Atlantic and Indo-Pacific corals. Among the former he actually found that *Acropora muricata* has a respiratory rate per unit of living tissue more than 18 times greater than *Siderastrea radians*. Both Vaughan (1930) and Verwey (1931) criticized these figures, which actually indicate a metabolic rate in *A. muricata* equivalent to that of a fish. Experiments carried out on the same species at the Tortugas (Yonge, 1937) indicated that a large proportion of the apparent utilization of oxygen by corals is actually due to oxidation of the mucus secreted by them during the course of the experiment. This varies greatly in different genera, being exceptionally high in species of *Acropora*, which literally drip mucus when removed from water, and being very low in *Siderastrea*. It is also increased at certain times, as during planulation in *Maeandra areolata*.

In view of this grave source of error it is impossible to accept at their face value figures which claim to represent either the absolute or the comparative rates of respiration in different corals, or general conclusions based on these figures. It is particularly unfortunate that Verwey based his conclusions on figures obtained from experiments on a species of *Acropora*. Furthermore, if the zoöxanthellae were not contained within the corals, these would excrete appreciable quantities of phosphate and ammonia into the surrounding water, which would thus be able to support a larger population of phytoplankton which would have the same effect of increasing the oxygen content of the water during the daytime. Association with zoöxanthellae is not necessary for ensuring oxygenation of the water in this way. Finally, corals are able to withstand temporary lowering of the oxygen tension without ill effects, experiments revealing that the oxygen content can fall to between 40- and 50-per cent saturation before respiration is affected (Yonge, Yonge and Nicholls, 1932). In lower oxygen tensions the rate of consumption steadily decreases but all the available oxygen is eventually utilized.

There is thus no evidence that the zoöxanthellae are essential to the corals either as a source of nutrition or of oxygen. There remains the fact that they act as automatic organs of excretion to the coral, removing as rapidly as it is formed all nitrogenous and phosphoric waste as well as the bulk of carbon dioxide. Experimental evidence concerning the significance of this is lacking and would not be easy to obtain, but it is not impossible that, by increasing the metabolic rate, it may be an essential factor in the remarkably rapid powers of skeleton formation possessed by corals (Stephenson and Stephenson, 1933). This is of vital importance in the formation and maintenance of reefs and it may be tentatively concluded that the association between corals and zoöxanthellae, essential to the plants but certainly not to *individual* coral colonies, may be an indispensable factor in the necessarily exceptional powers of growth and repair possessed by the marine *communities* known as coral reefs (Yonge, 1931*b*).

Spawning temperatures and distribution.—The horizontal distribution of reef-building corals is controlled by temperature. As stated by Vaughan

(1930), they live only in waters where the minimum temperature is not below 18° C. and the average temperature for the coldest month is not lower than about 22° C. It has usually been assumed that coral colonies are unable to live in colder water, that is, that the effect is on the individual. But data now available on the spawning temperatures of various species indicates that their distribution must in the first place be restricted by the temperature range within which reproduction can occur. The importance of this factor in the distribution of marine animals in temperate seas has been clearly demonstrated by a variety of investigators, as for example Orton (1920), Nelson (1928), and especially Runnström (1928, 1930, 1936).

The breeding temperatures of various species of Madreporaria were determined during the course of the Great Barrier Reef Expedition (Marshall and Stephenson, 1933). *Favia doreyensis* spawned in the early summer when the temperature was in the region of 30° C. *Symphyllia recta* and a species of *Lobophyllia* probably spawned about the same period. In a species of *Porites*, probably *P. haddoni*, breeding continued from January to May and, less actively, into July, although the absence of breeding during the rest of the year was not definitely determined. Breeding in *Pocillopora bulbosa* was discontinuous, occurring about the time of new moon in the months December to April, and at the time of full moon during July and August (winter), with a transition period in May to June. Although data were not obtained for the months September to November, it is possible that in this species spawning occurs discontinuously throughout the year. A similar discontinuous spawning at the time of the new moon in July and August was observed in *Maeandra areolata* at the Tortugas (Yonge, 1935*a*), while Abe (1937*a*) found a similar periodicity in the breeding of *Fungia actiniformis* var. *palawensis*, which planulated about the time of the new moon every month from September to April at Palao. In neither case was the incidence of breeding studied throughout the entire year.

Work on other reef invertebrates (Nicholls, 1931; Moorhouse, 1932; Stephenson, 1934) revealed that breeding may be confined to a short period in midsummer when the temperature is about 30° C. as for example in *Ophiothrix longipeda*, *Hippopus hippopus*, and *Cypraea annulus;* it may be continuous throughout the year as in *Thalamita stimpsoni*, *Myrionema amboinense*, and possibly *Trochus niloticus;* it may be continuous throughout the greater part of the year, from spring to autumn, with lunar periodicity at the time of the full moon in *Acanthozostera gemmata*, and finally, breeding may occur at two periods, in spring and again in autumn, as occurred in *Pinctada margaritifera* and *Tripneustes gratilla*.

It is clear that animals, such as the species of *Favia*, *Ophiothrix*, *Tippopus*, and *Cypraea*, which breed only in the hottest parts of the year will be confined to regions where temperatures of or near 30° C. are attained. The species which breed during the winter months, for example those of *Pocillopora* (possibly also *Porites*), *Thalamita*, *Myrionema*, and possibly *Trochus*, will be capable of living in much cooler water, when they may only breed during the summer months, while the species which breed from spring to autumn, for example *Acanthozostera* and, omitting the summer months, *Pinctada* and *Tripneustes*, will have a distribution intermediate between those of the other two groups.

It is possible that species which breed throughout the year may actually consist of two or more "physiological" races. Runnström (1928, 1930, 1936) has demonstrated that this is true of temperate species which have a wide distribution. For instance, *Ciona intestinalis*, which extends from the north boreal region to the Mediterranean, he found to consist of three physiological races: a boreal race which breeds from 6° C. to 18° C., a Mediterranean-boreal race breeding between 8° C. and 23° C., and a Mediterranean race breeding between 14° C. and 27° C.

We need to know a great deal more about the actual distribution of species of corals, about the range of temperature in different coral reef seas, and about the period of spawning of the different species in different areas. When this information is obtained, it is probable that correlations may be revealed between the distribution of corals and their spawning temperatures and that the presence of two or more physiological races may be revealed in those species which have the greatest horizontal range of distribution. The work which has already been done reveals that the old assumption that breeding must necessarily be continuous in the relatively stenothermal conditions of tropical seas (Orton, 1920) must be discarded.

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SOME ENZYMES OF THE NORTHWEST SHIPWORM, BANKIA SETACEA

By Robert C. Miller and Earl R. Norris

The wood-boring mollusks of the family Teredinidae represent an aberrant Lamellibranch group that has undergone a high degree of specialization both morphologically and physiologically in the process of adaptation to an unusual mode of life. The body has become greatly attenuated, and the shell reduced to a mere bivalve tool for excavating the wood, while the internal anatomy has undergone considerable modification, including displacement of organs occasioned by the elongation of the body and especially the development of a caecum of extraordinary size which is normally found filled with wood fragments ingested during boring. There is, in fact, no method by which the excavated wood can be ejected from the burrow except by passage through the digestive tract.

The question of whether the animals bore in wood for protection only, or whether they are able to utilize the carbohydrate of the wood as food, was investigated by Dore and Miller (1923), who found that 80 per cent of the cellulose and from 15 to 56 per cent of the hemicelluloses in Douglas Fir piling disappeared from the wood during its passage through the digestive tract of *Teredo navalis*. It was shown by Miller and Boynton (1926) that wood removed from the digestive tract (caecum) of *Bankia setacea* contained about four times the amount of reducing sugars in the original wood, and subsequently (Boynton and Miller, 1927) the presence of a cellulose-splitting enzyme was demonstrated in this species. The enzyme was shown not to occur in the crystalline style, which can easily be dissected out and tested independently, but was present in active concentration in an extract prepared from the digestive diverticula ("hepatopancreas") and certain adjacent tissues and organs.

Further investigations along this line have been carried out by the present authors, with certain alterations in technique. In particular, care has been exercised to dissect out the digestive diverticula in such a way as to include very little of the surrounding tissue.

The occurrence of a cellulase has been confirmed, and additional evidence secured of its origin in the digestive diverticula. Whether it occurs in the lumen of the diverticula, or only within the cells, has not been determined in these experiments. Potts (1923) and Yonge (1926) have described intracellular digestion in the walls of the digestive diverticula of related species.

The extract of digestive diverticula was also tested for other enzymes. Amylase, phosphatase, lipase, catalase, peroxidase, and urease were found to be present. Proteolytic enzymes of both peptic and tryptic types were tested for, but only a tryptic type enzyme was found, which was active at pH 8.

The crystalline style was found to contain amylase, confirming in *Bankia* the function of this structure as reported in other Lamellibranchs (Nelson, 1918). The style was tested for a number of other enzymes, none of which was found.

With regard to the occurrence of amylase in the digestive diverticula reported above, it should be stated that the *sheath* of the crystalline style is so closely associated with the digestive diverticula that no practicable method was found to separate it out. The style sheath accordingly presents itself as a possible source of the amylase attributed to the diverticula. The activity of the enzyme, however, indicated a concentration which was greater than would probably be derived from the relatively small amount of the sheath substance present.

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THE RESPONSE OF TREES TO CLIMATE

By Waldo S. Glock

Because the popular term "tree ring" is actually two-dimensional and probably misleading, two definitions are a necessary preface to the discussion which follows. *Growth layer* is the physiological, structural, and ecologic unit in a tree; it is the unit of growth, and consists of light wood and dense wood. An *annual increment,* a time or seasonal unit, is composed of one or more growth layers.

Up to the present, climatic information from tree growth has employed variations in the thickness of growth layers as a measure of rainfall variation, year for year. Such use assumes that each sharply distinct growth layer is an annual increment, that all layers are accurately dated back through the centuries, and that the amount of wood in a layer is so primarily dependent upon rainfall (or water supply) that it forms an accurate index of the rainfall. In other words, when rainfall records are available, amount of tree growth is expected to correlate to a high degree with amount of rainfall. Such correlation has been measurably successful only with trees grown under certain and rather restricted ecologic conditions. Study indicates, in any case, that the problem of correlation between tree growth and rainfall is not a simple one. Growth is a highly complex process. Several of the complexities may be cited: the season of effective rainfall; the time of cambial division; the time of cell enlargement; and the stimuli which initiate, control, and stop cambial division, cell enlargement, and wall thickening.

Because the present method of correlation between rainfall and tree growth necessitates exact dating to the year, and because its justification actually awaits extended research into the fundamentals of growth, an attempt has been made to observe tree growth under a sufficiently great variety of conditions to permit the detection of generalized pictures and generalized modes of response. The observations resulted directly from the following questions. Does tree growth have climatic significance whether growth layers are present or not? Does it have climatic significance, no matter what the type of growth, thickness of the layers, or nature of the sequence? The answer is held to be that all normal tree growth has climatic significance. It is evident, therefore, that the scope and range of climatic interpretations based upon tree growth will be materially increased if exact dating can be avoided and if the climatic significance of all normal tree growth can be established within limits.

Observation of the response of trees to climate, especially in respect to water supply as conditioned by rainfall, has proceeded chiefly with respect to response to type of rainfall and response to amount of rainfall. Correctly observed and formulated, the two kinds of approach become a historical method applicable to fossil woods. A brief outline of observations thus far is given here.

Rainfall type and growth response in trees.—In the American Southwest three distinct types have appeared. The first is characterized by winter rainfall; it may be called the *California type.* Most of the rainfall does not come during the season of growth. That is to say, water available for growth is due to previous accumulation and practically all the water the trees can obtain is present when growth begins. Hence, the growth period is unified and not intermittent. Annual increments are composed of single growth layers which are entire. Variability, although present among the layers of a sequence, is not striking.

The second type is characterized by summer rainfall; it may be called the *Texas type.* A large part of the rainfall which supplies water available for growth comes during the growing season. Wet and dry spells alternate and, if the dry spells are sufficiently intense, growth is arrested. Hence, growth is intermittently active. Annual increments may contain more than one growth layer. In other words, multiplicity typifies the Texas type whereas unity typifies the California type. Further, variability and partial layers characterize growth under summer rainfall.

The third type is intermediate because it has both winter and summer rainy seasons; it may be called the *Arizona type*. Water available for growth is due to previous accumulation, as in the winter rainfall type, augmented by growing-season rainfall, as in the summer rainfall type. Similarly, characteristics of the growth layers are intermediate. Growth begins on the basis of winter rainfall and may or may not be continued under the influence of summer rainfall. If it is not continued, the growth layer, or a series of growth layers, will resemble the California type. If it is continued, the growth layers will resemble the Texas type. As a matter of fact, ordinary layer sequences show a mingling of the two distinct types. It should be added that the California type of rainfall apparently stretches eastward at high altitudes and the Texas type stretches westward at lower altitudes. There is evidence to indicate that, through time, the types have shifted horizontally and vertically.

Quite naturally another type, continuous high rainfall, comes to mind. But it will be necessary to include factors other than growth type to distinguish this one from the California type.

Amount of rainfall and growth response in trees.—The generalized picture of growth response to water supply (and, through that supply, to rainfall) does not neglect the influence of other factors upon growth. It does, however, compare growth response with water as the chief variable.

The picture is bounded on the one hand by a water supply too meager for tree growth and on the other hand by a supply too abundant for tree growth. Within these limits there may be recognized three broad zones which merge along the areas of contact. The zones are well defined but not rigid. They not only shift through space and time, but also interpenetrate locally.

Within the *optimal zone,* water supply is constantly abundant. Trees obtain all the water they can use from year to year for the greatest possible growth in relation to other factors. Since water is constantly sufficient, such variations as do occur can induce no marked response in the trees. For this reason the optimal zone might be called the zone of no response. In brief, growth layers are characterized by uniform thicknesses, by a maximum average thickness, by minimum percentage variations, and by an absence of cycles.

The *minimal zone* lies below the optimal in the sense that it has less water. It has a restricted water supply of increasing degree with distance below the optimal zone. The trees do not obtain all the water they can use in relation to other factors. Since a decrease of water means less growth and an increase means more growth, the zone might be called the one of direct response. The less the average water supply, or rainfall, the greater the percentage of fluctuation from year to year, fluctuation which is closely paralleled by tree growth.

Among trees growing progressively farther below the optimal zone (i.e., with less and less water) the growth layers are characterized by increasing variability, by decreasing average thickness, by increasing percentage of variation, by increasing incidence of very thin layers, by an increase in the number of short cycles, and by progressively shorter cycles. Cross dating, if present, typifies a portion of the minimal zone only.

The *maximal zone* lies above the optimal and is marked by excessive water supply. The trees have access to more water than they can use, or need, in relation to other factors. Here, an increase in water means less growth and the zone, therefore, might be called the one of inverse response.

The evidence for responses and growth-layer types within the maximal zone is far less plentiful than that for the same things within the minimal zone. However, sufficient evidence does exist to indicate strongly that responses and growth-layer types vary progressively with distance above the optimal in much the same way that they vary downward in the minimal zone, except in an inverse direction.

Limitations of space do not permit either a complete description of the evidence upon which the generalized picture of growth response is based, or a list of the many examples which illustrate and clarify the picture, or the quantitative application of criteria. So far as determining past climate from fossil wood is concerned, the characteristics of tree growth under different types of rainfall and different amounts of water supply are fairly distinctive and rather readily decipherable.

PRE-TERTIARY ENVIRONMENTS AND THE VERTEBRATE RECORD

By Charles L. Camp

William Diller Matthew introduced his well-known thesis on Climate and Evolution with the following statement: "The theories of alternations of moist and uniform with arid and zonal climates, as elaborated by T. C. Chamberlain, are in exact accord with the course of evolution of land vertebrates, when interpreted with due regard for the gaps in the record." Matthew's views came chiefly from a study of the Cenozoic mammals and it may prove instructive to examine the pre-Tertiary vertebrate evidence in this connection. The vertebrate record alone will not give a complete picture, and must be studied with the help of the plants and the sedimentary record.

Interpretation of the evidence begins with a study of present-day life and the conditions under which it exists. Many of the environmental barriers enclosing ranges can be easily delimited. Thus, crocodilians, the larger land tortoises, and the larger lizards do not live where the ground freezes; the larger reptiles of the past were evidently so restricted. Their presence in the record indicates absence of a general or seasonal cold climate. The reptiles of today are relicts of the Mesozoic. They have not become essentially changed in anatomical structure, and their Mesozoic ancestors were doubtless subject to much the same physiological restrictions as the reptiles of today. The abundant sea reptiles of the past doubtless lived in warm seas and became stupified and helpless when they drifted into colder waters, just as do the recent sea turtles and sea snakes.

A peculiar physiological characteristic of modern lizards and snakes is their inability to withstand the direct rays of the summer sun for more than about ten minutes at a time. On torrid desert plains they must frequently seek the shade of bushes, rock crevices, holes in the ground, or they must bury themselves in the sand. This may tend to restrict their bodily size because with increase of size such protection becomes impossible in treeless desert areas. The largest desert lizards are certain African varanids which occupy burrows, and they do not occur in the central Sahara. A reasonable conclusion would be that the larger extinct reptiles were not desert dwellers, nor were they inhabitants of cold regions or even of the cooler seas.

But few warm-blooded vertebrates occur in the pre-Tertiary record. Most of the evidence must come from the fishes, amphibians, and reptiles. Among the reptiles we can most surely distinguish aquatic and flying forms with modified extremities from those forms adapted to various types of terrestrial life. We may also but less accurately determine fossorial, arboreal, soaring, bipedal, cursorial, and graviportal adaptations. This permits the recognition of habitats in the local environments. Unlike the reptiles, the amphibians and fishes of today are not always closely restricted by temperature. They range from the Arctic to the equator. But universally they require the presence of continuous moisture for their bodies and almost all of them even today, breed in water, and have doubtless always done so.

It may be that the Carboniferous coal swamps, presumably cool and moist, were more favorable for amphibians than for reptiles, whereas the Upper Pennsylvanian and Lower Permian red beds were more arid; and reptile bones predominate, while some of the amphibians there, such as *Eryops,* were modified for land life. Vertebrate skeletons have not been found immediately above the lowermost Permian of North America. Evidence from tracks indicates that a variety of primitive reptiles were present. Some of these were semiaquatic. Their tracks on foreset beds of the Coconino sandstone were made when the animals came in toward shore and are almost all directed up the slope of the beds. When they entered the water they evidently swam out without leaving tracks. We do not yet know to what ordinal groups these reptiles belonged, but some of them may have been short-footed therapsids, mammal-like reptiles such as occur so commonly in South Africa. There were a few stubby-toed amphibians and possibly some short-footed cotylosaurs. None of the reptiles were larger than a mastiff and the commoner forms were somewhat smaller than a house cat.

The close of the Coconino is marked by barren sand-dune beds. During the Upper Permian, reptiles were abundant in South Africa, also in European Russia, and in the Scottish lower Elgin, where semiarid conditions are indicated by the sediments and possibly by the growth of dermal plates and spines. These are much more prevalent in the Russian and Scottish reptiles than in those of Africa. The calcareous beds of the Karroo were doubtless laid down in swamps, but many upland animals were present there, as well as exceedingly abundant herbivorous forms, both large and small. Some of the lower Karroo carnivorous reptiles were over twenty feet in length.

The advent of a moister climate in the Lower Triassic is signalized by the development of a new group of stegocephalian amphibians. These stereospondyls occur almost simultaneously in Europe, Spitzbergen, Greenland, India, and North America. They are characterized by a pronounced flattening of the head and body, reduction of the limbs, and increase of cartilage at the expense of bone in the endoskeleton—degenerate features that would presumably accompany a lazy life in warm, still waters.

Reptiles and smaller amphibians in the Lower Moenkopi of Arizona are almost identical with those of the Bundsandstein of Europe. Great areas of sun-cracked mud flats occurred on what were doubtless flood plains and deltas; climate, probably moderate winters and a warm dry season with local rains.

The Upper Moenkopi contains a fauna of reptiles and larger amphibians, accompanied as in the Lower Moenkopi by the mud-flat-foraging *Chirotherium* tracks. Again, deltaic or flood-plain conditions in a semiarid environment are visualized. Salt crystals and gypsum are common in these upper beds. There was enough rain to bring sediments to cover the fresh tracks but not enough to obliterate all the tracks.

Above the Moenkopi lie extensive series of Upper Triassic sandstones, shales, and pebble beds, with a new fauna of crocodilelike phytosaurs and huge fresh-water amphibians. A marked change in sedimentation and in fauna is indicated. There is evidence of increased stream gradients and doubtfully some increase in humidity, as well as the development of more extensive flood plains over a previously shallow sea bottom.

The conglomeratic base of the Lower Chinle is followed by thick beds of bentonitic clays and sands containing an abundant fauna. A large anomodont reptile, large and small horned pseudosuchians, phytosaurs and amphibians, ferns, cycads, ephedras, and auracarian pines occur. A warm temperate or subtropical climate is indicated, doubtless with an arid season to allow for evaporation of shallow lakes. The region was watered by big rivers, draining volcanic districts. The deposits indicate flood plains and broad deltas traversed by slow-moving streams.

The Upper Chinle is a deposit of colloidal sediments, silts, gypsum, and fresh-water limestones. It was doubtless a more arid region of flood plains and broad, shallow lakes, subject to extensive periodic evaporation. The phytosaurs and smaller pseudosuchians are similar to those of the Lower Chinle, but the large horned pseudosuchians and anomodonts are absent and the amphibians are smaller and have nearly disappeared.

The Upper Chinle fauna is probably later than the Texas Dockum, coeval with the Dolores of Colorado and somewhat earlier than the Upper Newark. In the last named occur abundant small dinosaurs and coal beds, representing the end of the Triassic. Humid conditions in eastern America and aridity in the West doubtless prevailed and possibly a cool temperate climate resulting in the extinction of the phytosaurs and smaller pseudosuchians toward the end of the Triassic.

The lowermost Jurassic in the Southwest begins with fine-grained, orange-red sandstones containing the earliest crocodilians and dinosaurs. These are overlain by extensive beds of dune and channel sands, pond muds, limestones, and thick beds of gypsum—nearly barren but with some small bipedal dinosaurs, doubtless desert dwelling. Excessive aridity must have prevailed, especially in the area of the Navajo sandstone. Elsewhere in America nothing is known of the continental faunas of this period.

Considerable invasions of the sea appear later, followed by the Morrison swamp beds containing great sauropod dinosaurs, small long-legged crocodilians, rhynchosephalians, and early mammals of Upper Jurassic age. Probably a widespread humid, subtropical environment is to be postulated. The dinosaurs of other parts of the world were similar. They were doubtless derived from upland forms, of which we know so little.

The advent of the Cretaceous in North America marks the near extermination of Sauropods, which persisted until much later in the Southern Hemisphere. There is indication of increasing emergence and aridity followed by extreme submergence and humidity tending toward tropical conditions in the Upper Cretaceous. Entirely new groups of dinosaurs enter the North. The warm shallow seas were inhabited by plesiosaurs, mosasaurs, marine crocodilians, and swimming birds. Over the waters soared the giant pterodactyls, and a wealth of tropical life flourished at the close of the period when, with the Laramide revolution, the larger forms, except for turtles and crocodilians, were completely cut off. The Paleocene brings the early placental mammals in abundance, together with great accumulations of gravel, sandstone, and silt from newly elevated regions.

This succession of climates, so far as it can be visualized, shows an alternation of continental conditions from the cool-temperate coal swamps of the Pennsylvanian, through an increasingly arid Lower and Middle Permian to a warmer, wetter Lower Triassic, thence gradually through first a humid and then an increasingly arid Upper Triassic into an extremely arid Lower Jurassic followed by local submergences and a humid subtropical Upper Jurassic, thence to a cooler, more arid Lower Cretaceous, and finally to a climax of widespread submergence and tropical humidity in the Upper Cretaceous.

The succession of North American faunas living under these environments are:

1. Humid, probably cool-temperate, coal-swamp Pennsylvanian faunas with a predominance of small primitive amphibians similar to those of Europe.
2. Red-bed Upper Pennsylvanian and extreme Lower Permian faunas with a predominance of archaic reptiles and advanced rhachitmous amphibians. Scattered representatives of these are found in Europe and a few of the pelycosaurs persist until the Upper Permian in South Africa. The advent of the more arid Permian apparently stimulated the development of the reptiles and gave rise to more distinctly land-living amphibians.
3. Abundant tracks of unidentified, smaller reptiles and amphibians in beds above the lowermost Permian—possibly into the Upper Permian. These occur mostly in subaqueous red beds and cross-bedded sandstones which are followed in places by barren dune sands and marine incursions.

4. Red-bed Lower Triassic, primitive bipedal thecodont reptiles and an early, aquatic, stereospondylous amphibian close to or identical with *Capitosaurus semiclausus* of the European Buntsandstein. Some of these appear much later in South America and South Africa. Local marine incursions occur in the Southwest.

5. Red-bed Upper Triassic advanced thecodont and large anomodont reptiles associated with late stereospondylous amphibians, corresponding to genera found in the European Lower Keuper and the Upper Elgin of Scotland.

6. A primitive crocodilian and large dinosaur tracks in Arizona red beds, presumably of lowermost Jurassic age.

7. Small, primitive, bipedal dinosaurs from Lower Jurassic desert sandstones in Arizona. Extremely arid climates were evidently widespread at this time.

8. A barren interval followed by giant warm-swamp sauropods in the Morrison Upper Jurassic associated with rare crocodilians, rhynchocephalians, and primitive mammals.

9. Marsh dinosaurs, including rare survivors of the Morrison types in the North, coal beds, and trees with annular rings indicating pronounced seasonal differences.

10. Lagoon and swamp-living dinosaurs in the semitropical Upper Cretaceous of the Cordilleran region and California. These faunas are of wide distribution in the Northern Hemisphere.

The North American sequence is paralleled by that of Europe. The earliest Carboniferous (Mississippian) amphibians of Great Britain have not been found elsewhere. Those of the Pennsylvanian of Ireland and Bohemia are closely related to the North American forms. The isolated Lower Permian continental basins of Europe contain more or less distinct vertebrate faunas corresponding roughly to those of North America and Kashmir. In the Middle Permian or lower Upper Permian of Russia the mammal-like reptiles first appear. They probably antedate those of South Africa. The Scottish lower Elgin and the Russian Tartarian contain distinctly *Cistecephalus* zone Karroo types of anomodonts and Parieasaurs. The North American deposits of this period, if present, are barren.

Lower Triassic faunas of Europe and North America are much alike. Those of the Karroo are entirely different and have identical representatives in Asia. The Middle Triassic of Europe is represented in India and South Africa by its amphibian fauna. Land vertebrate fossils of this age are unknown in North America.

The Upper Triassic faunas of North and South America and Europe are similar in some of their elements, unlike in others. Large specialized anomodonts are found in North and South America and in the East African Karroo, not in Europe. Quite different forms appear in Africa. Phytosaurs are alike in Europe and North America. They do not occur in the south. The large stereospondyls of North America are close to, or identical with, the European *Metoposaurus*. The wealth of therapsid, especially gorgonopsian and cynodont, reptiles of Africa has not yet been discovered elsewhere except in South America, where the families are different.

The Lower Jurassic of North America contains a crocodilian comparable to some of the European and African forms. The Upper Jurassic of North America has its counterpart in the East African Tendaguru, and in much later deposits in South America, Australia, Asia, and India.

The Lower Cretaceous of the two hemispheres has but little in common; the Upper Cretaceous is similar throughout the north.

In general it appears that the sequence of European climates must agree fairly closely with those of North America; that the South American climate of the Upper Triassic in the latitude of extreme southern Brazil was similar to that of the Northern Hemisphere at that time, and to that of equatorial East Africa. The uppermost Triassic (Molteno) of South Africa resembled that of Australia in its flora and was possibly cooler than the north, as no reptiles are found in it. The lower Jurassic of South Africa (Stormberg) was evidently similar to that of the Northern Hemisphere as it had some identical elements in its faunas and many similar ones.

Unquestionably, the Lower Permian or Upper Carboniferous of South Africa, and of the Southern Hemisphere generally, was cooler and probably it was more humid than in the north. No reptiles, except one marine or brackish-water form, appear in the Southern Hemisphere until Upper Permian time, although the sediments are thick and widespread. The *Tapinocephalus* zone of the Karroo, some 12,000 feet above the base of that series, contains highly developed reptiles which are undoubtedly Upper Permian in age and which evidently lived under more favorable conditions (warmer and wetter) than those of Europe. The same may be said of the lower Triassic of South Africa and central Asia, where some of the reptiles are evidently peculiarly adapted to lake and swamp life and some are advanced in the direction of mammalian evolution.

Possibly the appearance of waves of glaciation in the Southern Hemisphere coincided in the north with peculiar cycles of sedimentation such as the cyclothems of Illinois and the alternation of widespread, thin marine limestones with continental shales and sandstones in New Mexico, Texas, and Kansas. The south, then, was much slower to develop the milder climates of the north, and its vertebrate faunas were late in appearing. When they did come, in the Upper Permian, they evidently found conditions more favorable, especially during the late Permian and Triassic, than in North America and Europe. A gradual similarity of world climates in both north and south was evidently achieved during the Jurassic and Cretaceous and the extinction of reptiles at the end of the Cretaceous was apparently world-wide and remarkably rapid.

This general picture may now be superimposed upon a more speculative background: the origin of the main types of vertebrate structure.

The architecture of the primitive vertebrates is determined largely by anatomical mechanisms developed for efficient locomotion. The essential features of this structure are: bilateral symmetry in connection with anteriorly directed movement; a central, stiffening, skeletal axis; anterior concentration of sense organs and nervous system; and feeding and respiratory organs interconnected and located anteriorly. This mechanism enabled the vertebrates to swim in flowing waters, particularly fresh-water streams. The appearance of the earliest vertebrates in fresh-water deposits is significant, and their long Ordovician-Devonian history may be traced mainly to this habitat.

The first attempts at land life by the crossopterygian fishes of the Upper Devonian may be correlated with the development of widespread, seasonal arid climates in that period. The seasonal drying of streams brought the necessity of migration between water holes along intermittent stream courses and eventually from one stream to another. This marks the origin of the change from fin to limb; from fresh-water fish to amphibian. Skull structures and fishlike feeding habits were not modified until later, when the land plants and invertebrates became better established and provided a new food supply.

Again, climatic aridity at the end of the Pennsylvanian marks the first appearance of the reptiles—vertebrates which for the first time became entirely independent of aquatic life even for breeding purposes. The lower Upper Permian, with its development of numerous herbivorous reptiles, marks the point at which the carnivorous predators began to acquire mammalian characteristics—by shortening of the jaws, differentiation of the teeth, and increase of running ability with vertical placement of the limbs and consequent shortening of the toes.

Locomotor mechanisms became still more efficient in the Triassic with the development of bipedalism for running on the hind feet across mud flats, and from such forms as these came the earliest dinosaurs which arose as bipedal animals. The arid Lower Jurassic permitted the survival of small bipedal dinosaurs dwelling among the sand dunes, and it witnessed the rise of the small lizardlike rhynchocephalians as well as of the lizards themselves.

Floral changes at the end of the Triassic accompanied the rise of archaic herbivorous mammals—the multituberculates; but the slowness of mammalian development during the Jurassic and Cretaceous has not been satisfactorily explained. It may be, as Matthew believed, that subtropical humid climates are unfavorable to mammalian evolution.

The origin of the major vertebrate groups may then be correlated with a series of secular environmental changes from the Ordovician to the present. The gradual widespread climatic alternations of geologic time must certainly accompany the rise of the great groups of plants and animals. Such alternations have tended to handicap specialized forms and to put a survival premium upon adaptability. Physiological and structural adaptability have evidently been of greater survival value than specialization during times of rigorous climatic change. Specialization has favored survival under conditions of climatic uniformity. Many highly specialized vertebrates evidently succumbed to the climatic stress of the Pleistocene. Man, on the other hand, a superadaptable organism, is a product of that epoch.

THE PAST CLIMATES OF NORTH CHINA SINCE THE LOWER CRETACEOUS

By P. Teilhard de Chardin

Continentally speaking, modern North China begins with the Cretaceous. Long before, of course—as early as the Late Carboniferous—did the land decidedly emerge there above the sea. But whatever may have been the Triassic and Jurassic physiographic features of the region, they have been mostly destroyed by the Late Jurassic (main "Yenshan") tectonic revolution. Since the Lower Cretaceous, on the contrary, and still better since the Upper Cretaceous (i.e., after the huge acid outbursts characterizing the younger Yenshan movements), a definite land platform becomes recognizable, more or less warped and faulted by subsequent movements, but still preserving today the traces of an ancient topography.

With the Cretaceous we accede, first in Mongolia and later in China proper, to the stage (subfinal in continental geology) of basin formation.

Starting from this natural divide, let us try to figure the nature and the changes of climatic conditions on one of the most ancient continental areas of the world.

A Short Review of the Climatic Evidences

As a basis for further speculations we must first collect and study for each geological period in North China the data likely to have, for this particular period, a climatic significance. So far as our present knowledge goes, the facts are as follows:

a) *Lower Cretaceous.* In contrast with the generalized swampy conditions prevailing all over China (except Mongolia) during the Jurassic, the Lower Cretaceous lakes of North China had restricted and definite boundaries. Remains of Fish (*Lycoptera*) abundant. No typical subaerial deposits reported so far. Coniferous trees abundant, and the last Cycads.

Important tectonic break with granitic intrusions and rhyolitic extrusions (outside of Mongolia).

b) *Upper Cretaceous.* Lakes distinctly reduced. Subaerial deposits well represented, if not dominant : mostly red concretionary clays, associated perhaps with loess in Mongolia. Coniferous trees.

Tectonic break. Conglomerates.

e) *Eocene and Oligocene.* Lakes probably still more reduced. Red concretionary clays on the slopes of the basins. An increase in aridity is suggested by local accumulation of gypsum (Shansi . . .) and by an abundance of wind-worn residual pebbles (Mongolia). A rich mammalian fauna (*Titanotherium* fauna) is thriving, nevertheless, from Outer Mongolia down to Yunnan and even Burma. Silicified trees fairly common in Mongolia.

d) *Late Oligocene or Lower Miocene* (*Aquitanian*). Conditions perhaps essentially the same as before, except that the trend of the fauna seems to assume a distinct east–west (zonal) orientation. *Baluchitherium* fauna. Appearance of a number of *Ochotona*-like Rodents. Last (?) Crocodiles.

Important tectonic break.

e) *Upper Miocene.* A temporary increase of the lakes is probable in Mongolia as well as in China, and the fauna is deeply rejuvenated by migratory elements : Giraffidae, Mastodontidae, Equidae . . . , associated with primitive Deer. First *Ochotona*. First *Lamprotula*-like Unionidae (in Mongolia). Flora decidedly temperate, but with subtropical relicts. (See R. Chaney.)

New tectonic break, and fresh uplift of the inland platform.

f) *Pontian.* Lakes reduced. Very thick concretionary clays on the slopes.

A rich steppe- and bush-fauna (*Hipparion* fauna). Appearance of Melidae and Canidae. First *Gazella* and Siphneidae (*Prosiphneus*).

g) *Middle Pliocene.* A maximum of the Pliocene lakes. Cyprinid Fishes. A sudden development of autochthonous strepsicerine Antelopes, and of Munjack-like Deer, these latter ones (found in association with Rusa and Axis) suggesting rather easy communications with the South. Plenty of Gazellas.

A moderate tectonic uplift.

h) *Villafranchian.* No more lakes in Mongolia. Lake deposits and red concretionary clays in China proper. Pliocene fauna impoverished, but first appearance of Horse and Camel (from East), Bison (from South ?), polyclad Deer (from West). First true *Meles* and *Siphneus.* Maximum of the *Lamprotula* (tuberculated, thick-shelled Unionids). *Stegodon* retreat south of the Tsinling range, into the Yangtze basin. *Populus euphratica* in West China (Sinkiang) and in the Lower Huangho basin.

A strong uplift (and local warping) of the inland platform. Opening of the gorges, and dessication of the lakes.

i) *Early Pleistocene.* Practically no more lake deposits on the Shansi platform, but thick reddish concretionary clays along the slopes (soligluxion). First terrace. Mammalian fauna sharply differentiated north and south of the Tsinling range. Appearance of euryceroid Deer, Water Buffalo, Man.

j) *Late Pleistocene.* Sharp replacement of the red or reddish concretionary clays by light-colored sediments (loess, sand dunes). Extensive temporary lakes or nors in Mongolia and West China. Fauna distinctly reduced, typically palaearctic. Water Buffalo still living as far north as Harbin, in contact with Moose and woolly Mammoth. The *Lamprotula* survive in the maritime plain, but have mostly shifted into the Yangtze basin.

A gradual transition to the Holocene time is represented by an accumulation of black earths in Manchuria and by a marked reduction of the nors in Mongolia.

A TENTATIVE INTERPRETATION

Now if we try to grasp the meaning of the above-related facts in the line of climatic evolution, we are led to the following conclusions:

1. In North China during and since the Lower Cretaceous the climate was never a tropical one. No traces of lateritic soils are observable anywhere in the sediments, nor any remains of decidedly warm flora. For instance, the complete absence of palm trees amongst a harvest of silicified woods is conspicuous.[1]

2. Judging from the abundance and from the persistence of the red concretionary clays, the conditions, up to the end of the Early Pleistocene, were dominantly semiarid, although warmer than today. This assumption does not conflict with the presence of numerous lakes at the bottom of the basins, and it is supported by the characters of the mammalian fauna in which decidedly steppe-living forms are recognizable since at least the Aquitanian.

3. Indication of repeated cycles of moister climates is given by a periodic increase of the lake deposits (Upper Miocene, Middle Pliocene, Villafranchian . . .). But these minor oscillations do not seem to express the most essential trend of climatic evolution over the considered area. Fundamentally, the climatic history of North China since the Lower Cretaceous can be regarded *as a slow but steady shifting of the Asiatic platform toward increasingly cool and desertic conditions.*

This continuous advance toward cold and dessication is already recognizable before the Cretaceous (no lateritic soils occur after the Permian; Cycads decreasing after the Jurassic . . .). During the post-Cretaceous times, the process becomes more and more clearly expressed in such features as: the development of desertic soils in the sediments; the progressive reduction of the lakes (from Mongolia southward); the diminution, and finally the complete disappearance of the red color in the subaerial deposits; the gradual dominance of steppe-living forms in the fauna; the presence as early as in the Pliocene of such a typical modern central asiatic tree as *Populus euphratica;* the more and more zonal (east–west) distribution of the fauna, and its final breaking into two distinct units, north and south of the Tsinling Range, etc. The climax of this long transformation is well marked in the Pleistocene appearance of the "yellow earth" (loess, sands), and also of the black earths of Manchuria—not a temporary and fortuitous event, I believe, but the natural end or turning point of a protracted continental evolution. It should really seem that we are carried on by a fundamentally single swing from Late Mesozoic to modern time in China.

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[1] Leaves of *Sabalites* are, however, recorded from the Lower Cenozoic of Japan and Manchuria.

A first explanation of this important phenomenon has surely to be searched for in tectonic causes. We know positively that since the end of the Paleozoic the asiatic platform has been constantly rising, although by irregular steps or "saccades." As a consequence, North China never was so high above the sea, never so rugged, as today. Hence its increasingly desertic face, exactly paralleling its increasingly continental conditions.

As a further step it will remain to determine whether this local explanation can be generalized to other continental areas in the world, and how much it has to be combined with such pan-geic factors as general cooling of the earth since the Mesozoic times.

Whatever should be decided in this line, the climatic case of North China is a warning to the geologist that his study of the earth cannot be restricted to the devising of some uniform law of periodic marine transgressions. Spanning entire groups of the so-called geologic periods, or even perhaps covering the whole geologic sequence, some other much larger natural processes are at work which express the real history of our planet: such are the general evolutions of continents, climate, and life.

Appendix

An abbreviated list of the sedimentary and biological facts pointing to a general cooling of the climate in North China since the Lower Cretaceous. Dotted lines represent tectonic uplift.

Holocene. Extreme reduction of the nors in Mongolia and West China. Dominance of black earths in Manchuria.

Late Pleistocene. Loess and sand dunes. *Lamprotula* practically restricted to the Yangtze basin. Maximum of the zonal (east–west) distribution in the mammalian fauna. Moose and Mammoth in Manchuria.

Early Pleistocene. Latest red concretionary clays. First Euryceroid Deer and Water Buffalo. Appearance of Man. A practically complete separation between a north Chinese and a south Chinese fauna.

....

Villafranchian. Latest lakes in China proper. Maximum of the *Lamprotula* in North China. *Stegodon* restricted to the south of the Tsinling Range. Plenty of Gazellas. First true *Siphneus* (Mole Rats). *Populus euphratica* in Sinkiang and North Honan.

....

Middle Pliocene. Latest lakes in Mongolia. Pliocene lakes at their deepest in Shansi. Maximum of the strepsicerine Antelopes and Munjack-like Deer. Rusa, Axis. Many Gazellas.

Pontian. Further invasion of the southwestern fauna. First Siphneidae and Gazellas. *Hipparion* (from America).

....

Upper Miocene. First invasion of a southwestern fauna (Proboscidians, Giraffidae . . .). First *Ochotona* and first *Lamprotula.*

....

Aquitanian. First Ochotonoidea. First clear indication of a zonal (east–west) distribution of the mammalian fauna.

............?...........

Oligocene and Eocene. Mammalian fauna almost uniform from North to South China. Red concretionary clays, gypsum.

....

Upper Cretaceous. First true red concretionary red clays. Loess (?) in Mongolia. Dinosauria.

....

Lower Cretaceous. First clearly limited lakes and basins.

FLORAL CHANGE DURING THE CENOZOIC ERA IN THE JAPANESE ISLANDS

By Hisakatsu Yabe and Seidô Endô

In the Japanese Islands a land condition prevailed in the Cretaceous Tertiary interval, and the succeeding Palaeogene was in large part a period of coal formation, to which is due the rich store of good coal in the many coal fields of Karahuto (Saghalien), Hokkaidô, Honsyû (the main island), and Kyûsyû; the coal formation was paralic, being often intervened by marine sediments.

The Palaeogene Isikari series in Hokkaidô has a flora in its lowest division, the Noborikawa coal-bearing beds, which yielded species identical with or very close to:

Fagus Antipofii Heer
Betulites Snowii Lesquereux
Populus (Trochodendroides) arctica Heer
P. (T.) Zaddachi Heer
Cinnamomum obovatus Berry
Celastrus Taurinensis Ward
Knightiophyllum wilcoxianum Berry

In addition there are species belonging to *Populites, Magnolia, Quercus, Platanus,* and *Ficus.* The flora recalls the Laramie flora of North America.

The Noborikawa beds are overlain by the Horokabetu shale, which is succeeded by the Yûbari coal-bearing beds with a similar flora, comprising:

Osmunda Heerii Gaudin
Glyptostrobus europaeus Heer
G. Ungeri Heer
Populus (Trochodendroides) nervosa var. *elongata* Newberry
P. (T.) arctica Heer
Castanea Ungeri Heer
Laurus primigenia Unger
Fagus castaneaefolia Unger
Vibrunum cuneatum Newberry
Fagus Antipofii Heer
Betula atavina Heer
B. vetusta Heer
Alnus kefersteinii Goeppert
Fraxinus macrophylla Heer
Celastrus borealis Heer
Salix varians Goeppert

The Yûbari beds are overlain by the marine Wakkanappe shale and Wakkanappe sandstone, the Bibai coal-bearing beds, the Lower *Corbicula* beds, the *Woodwardia* zone, and the Ikusyûnbetu coal-bearing beds; all being conformable with one another. These deposits are rich in fossils and the flora is essentially similar to the so-called Arctic Miocene flora of O. Heer or approximately to the Kenai flora of Alaska. Most typical is the *Woodwardia* zone.

Fossil Plants from the Woodwardia Zone

Aspidium oerstedi Heer
Dennstaedtia americana Knowlton
Lastraea japonica Kryshtofovich
Osmunda sp.
Woodwardia ezoana Endô
Glyptostrobus europaeus Heer
Sequoia chinensis Endô
Alisma paucinervis Heer
Iris latifolia Heer
Musophyllum sp.
Acer arcticum Heer
Alnus kefersteinii (Goeppert)
Betula Brongniarti Ettingshausen
Carya antiquorum Newberry
Celastrus borealis Heer
Corylus insignis Heer
Ficus occidentalis Lesquereux
Hedera Macclurii Heer
Idesia polycarpa Maximowicz
Juglans nigella Heer
Leguminosites sp.
Macclintockia sp.
Nyssa arctica Heer
Paliurus columbi Heer
Platanus aceroides Goeppert
Prunus serrulata Heer
Populus (Trochodendroides) cuneata Newberry
P. (T.) latior Al. Braun
P. (T.) speciosa Ward
P. (T.) Richardsoni Heer
P. (T.) Zaddachi Heer
Zizyphus falcatus Berry
Zizyphus Meigsii Berry
Asplenium tenellum Knowlton
Equisetum arcticum Heer
Osmunda affinis Lesquereux
Onoclea hebraidica Gardner
Ginkgo adiantoides (Unger)
Sequoia langsdorfii (Brongniart)
Taxodium distichum miocenum Heer
Carex sp.
Musophyllum complicatum Lesquereux
Sabalites nipponicus Endô

FOSSIL PLANTS FROM THE WOODWARDIA ZONE—*Continued*

Alangium platanifolium var. *macrophyllum* Wang
Banisteria pseudolaurifolia Berry
Büttneria aequalifolia Fr. Meyer
Castanea Ungeri Heer
Cinnamomum lanceolatum (Unger)
Corylus Macquarrii (Forbes)
Ficus tiliaefolia Heer
Hibiscus n. sp.
Juglans alkalina Lesquereux
Laurus Schmidtiana Heer
Liquidambar formosana Hance
Mallotus n. sp.
Nelumbo nipponica Endô
Planera Ungeri Ettingshausen
Platanus Guillelmae Goeppert
Populus (*Trochodendroides*) *arctica* Heer
P. (*T.*) *glandulifera* Heer
P. (*T.*) *mutabilis* Heer
P. (*T.*) *subrotundata* Lesquereux
P. (*T.*) *xantholithensis* Knowlton
Viburnum Nordenskiöldi Heer
Zizyphus Meekii Lesquereux

In the flora of the *Woodwardia* zone, *Woodwardia* with abundant individuals, *Iris, Musophyllum,* and *Ficus* are foreign to the typical Arctic Miocene flora. In the older Bibai coal-bearing beds there are, moreover, *Sabalites* and *Nelumbo.*

The Ikusyunbetu beds are overlain by the Upper *Corbicula* beds, which are succeeded by the Asibetu coal-bearing beds as the youngest member of the Isikari series. This, as well as the Urahoro series of the Kusiro-Tokati coal field, which is approximately contemporaneous with the former, have such Arctic Miocene flora elements as:

Nelumbo nipponica Endô
Fagus Antipofii Heer
Quercus sp.
Liquidambar formosana Hance
Hedera sp.
Cinnamomum sp.
Betula sp.
Castanea sp.
Sequoia langsdorfii (Brongniart)

PARTIAL LIST OF FOSSIL PLANTS FROM THE URAHORO SERIES

Taxodium dubium Heer
Glyptostrobus europaeus Heer
Sequoia langsdorfii (Brongniart)
Salix varians Goeppert
Juglans acuminata Al. Braun
Betula grandifolia Ettingshausen
Betula ? sp.
Corylus Macquarii (Forbes)
Carpinus grandis Unger
Ulmus plurinervia Unger
Ulmus ? sp. (cf. *Rhamnus gravelini* Heer ?)
Ficus sp. (*F.* cf. *tiliaefolia* Heer)
Populus (*Trochodendroides*) *Richardsoni* Heer
P. (*T.*) *arctica* Heer
P. (*T.*) *Zaddachi* Heer
Platanus aceroides Goeppert
Acer arcticum Heer
Paliurus ? *borealis* Heer
Zizyphus ? sp.
Vitis Heeriana (Knowlton)
Vitis sp.
Viburnum ? sp.
Musophyllum sp.

The Ōtuzi coal-bearing series of the middle division of the Palaeogene of Kyûsyû, although believed to be almost contemporaneous with the Bibai-Ikusyûnbetu coal-bearing beds of Hokkaidô, has almost no elements of the Arctic Miocene flora, but on the contrary yields *Acrostichum, Lastraea, Sabalites,* and *Nelumbo,* besides *Sequoia* and *Taxodioxylon sequoianum* Gothan. Compared with the Isikari flora, the Ōtuzi flora is decidedly southern in aspect.

Vegetation more or less similar to the Arctic Miocene flora continued in Hakkaidô to the basal part of the Kawabata series and in Saghalien to its upper part. The best examples of the former are found in the flora of the Esutoru coal-bearing beds of the Esutoru coal mines in Japanese Saghalien, and in the Dui coal-bearing beds of Russian Saghalien; this basal Miocene flora, with a general aspect of the Palaeogene flora, bears new elements such as *Betula sachalinensis* Heer and *Acer ambiguum* Heer. It is noteworthy that the Dui flora contains *Comptoniphyllum Anderssoni* Florin and *C. Naumanni* Nathorst; the former species was first described from the Eocene of Fushun, Manchuria, while the latter is characteristic and widespread in the lower Neogene flora of Honsyû.

FOSSIL PLANTS FROM THE DUI COAL-BEARING BEDS AND THE ESUTORU COAL-BEARING BEDS

	DUI	ESUTORU
Equisetum arcticum Heer	–	x
Glyptostrubus europaeus Heer	–	x
Sequoia langsdorfii (Brongniart)	x	x
Taxodium distichum miocenum Heer	x	x
T. tinajorum Heer	–	x
Acer trilobatum Al. Braun	x	–
A. sp., seed	x	–
A. ? Sterculia ?	–	x
Aesculus sp.	–	x
Alnus kefersteinii Unger	x	–
Betula Brongniarti Ettingshausen	x	x
B. elliptica Saporta	x	–
B. prisca Ettingshausen	x	–
B. cf. *macrophylla* Goeppert	x	–
B. sachalinensis Heer	x	–
B. sp.	–	x
Carpinus grandis Unger	x	x
Castanea atavia Unger	x	–
Cerastrus sp. (*C.* cf. *borealis* Heer)	x	–
Comptoniphyllum Naumanni Nathorst	x	–
C. Anderssoni Florin	x	–
Corylus Macquarrii Heer	–	x
Crataegus cf. *kornerupi* Heer	x	–
Cupania longipes Heer	x	x
Fagus Antipofii Heer	x	x
Ficus tiliaefolia Heer	–	x
F. cf. *tiliaefolia* Heer	x	–
Hedera sp.	x	–
Juglans nigella Heer	x	–
J. cf. *rostrata* Goeppert	x	–
J. (*Carya*) *picroides* Heer	x	–
Liquidambar formosana Hance	x	–
Magnolia Nordenskiöldi ? Heer	x	–
Musophyllum sp.	–	x
Nelumbo nipponica Endô	x	x
Platanus Guillelmae Goeppert	–	x
Populus balsamoides Goeppert	x	–
P. cf. *latior* Al. Braun	–	x
Quercus drymeia ? Unger	x	–
Salix sp.	–	x
Sophora Schmidtiana Heer	x	–
Trapa borealis Heer	x	x
Tilia sachalinensis Heer	x	x
Ulmus plurinervia Unger	x	x

The Naihoro flora of the Naihoro coal-bearing beds in Japanese Saghalien, the stratigraphical position of which may be near the top of the Kawabata series, although not yet fully known, has *Sequoia* sp. [*S. langsdorfii* (Brongniart)], *Ficus tiliaefolia* Heer ? (similar to the form in the Esutoru flora), and *Ficus* sp., beside *Alnus* and *Carpinus;* its general aspect is related to that of the Esutoru flora and the Palaeogene flora of Hokkaidô and Saghalien rather than that of the Neogene flora of Honsyû.

The basal Miocene or Oligo-Miocene flora of Honsyû is typified by the flora of Oguni (Yamagata Prefecture), Kannonzawa (Niigata Prefecture), Daigo (Ebaragi Prefecture), and Yatuo (Toyama Prefecture), while in a little younger position is the Hiramaki flora (Gihu Prefecture) and Sirakawa flora (Hyôgo Prefecture). Both older and younger floras are characterized by the rarity of *Sequoia* and *Taxodium* and by the frequent occurrence of *Quercus* (especially evergreen types), *Cinnamomum, Mallotus, Hibiscus, Comptoniphyllum, Liquidambar,* and other warm temperate forms. Furthermore, many of the species are now living in present-day Japan, in which respect the basal Neogene floras differ considerably from the older ones.

Fossil Plants from the Basal Miocene of Oguni, Kannonzawa, and Daigo

	OGUNI	KANNONZAWA	DAIGO
Aspidium sp.	x	–	–
Blechnum nipponicum Makino	x	–	–
Equisetum sp.	x	–	–
Lygodium cf. *Kaulfussii* Heer	–	x	–
Pteris prestwichii Ettingshausen	–	x	–
P. oeningensis Al. Braun	–	x	–
Glyptostrobus ? europaeus Heer	x	–	–
Libocedrus Lantenoisii Laurent	–	x	–
Pinus hepios Unger	x	x	–
P. timleri Kinkelin	–	x	–
P. sp.	x	x	–
Sequoia sp.	–	–	x
Taxites sp.	–	x	–
Taxodium distichum miocenum Heer	x	–	–
Taxus baccata Linné	–	x	–
Arundo pseudogoepperti Berry	x	x	–
Cyperites sp.	x	–	x
Acer sp., (seed)	–	–	x
Antholites oguniensis Morita	x	–	–
Antholithes amaenus Lesquereux	x	–	–
Apeibopsis discolor Lesquereux	x	–	–
Araliphyllum Naumanni Nathorst	–	x	–
Bauhinia sp.	x	–	–
Bumelia sp.	x	–	–
Betula prisca Heer	x	–	–
B. ulmifolia Siebold et Zuccarini	x	–	–
Benzoin antiquum Heer	x	–	–
Buxus japonica Müller	x	–	–
Carpolithus Braunii Heer	–	x	–
Castanea miocenum Morita	x	x	–
C. sp.	–	x	–
C. Kubinyi Kovats	x	–	–
C. Ungeri Heer	x	x	–
C. vulgaris Lamarck	x	–	–
Caesalpinia Falconeri Heer	x	–	–
C. obovata Heer	x	–	–
Camellia japonica Linné	x	x	–
Carpinus cuspidata Saporta	x	–	–
C. grandis Unger	x	–	–
C. sp.	x	x	–
C. yedoensis Maximowicz	x	–	–
C. laxiflora Blume	x	–	–
Cinnamomum polymorphum Al. Braun	x	–	–
C. oguniense Morita	x	–	–
C. miocenum Morita	x	–	–
C. lanceolatum Unger	x	–	–
C. cf. *Scheuchzeri* Heer	x	–	–
C. sp.	x	–	–
Celastrus sp.	–	x	–
C. lanceolatus Friedlich	x	–	–
Cassia ambigua Heer	x	–	–
C. feronioe Ettingshausen	x	–	–
Cercis antiqua Saporta	–	x	–
C. japonica Kryshtofovich	–	x	–
C. sp.	x	–	–
Comptoniphyllum Naumanni Nathorst	x	x	x
Cornus studeri Heer	–	x	–
Diospyros kaki Linné	x	–	–
D. brachysepara Al. Braun	x	–	–
Dryophyllum Dewalquei Saporta et Marion	x	–	–
D. Oishii Morita	–	x	–
Dryandroides lignitum Ettingshausen	x	–	–
D. hakeaefolia Unger	x	–	–
Dryophyllum sp.	–	x	x
Eloeoguus acuminatus Weber	x	–	–

Fossil Plants from the Basal Miocene of Oguni, Kannonzawa, and Daigo—*Continued*

	OGUNI	KANNONZAWA	DAIGO
Elaeocarpus photiniaefolia Hooker et Arnott	–	x	–
Ficus multinervis Heer	x	–	–
F. obtusata Heer	x	–	–
F. Ungeri Lesquereux	x	–	–
F. subtruncata Lesquereux	x	–	–
F. sp.	x	–	–
Fagara sp.	x	–	–
Fraxinus longicuspis Siebold et Zuccarini	x	x	–
F. primigenia Unger	x	–	–
F. praedicta Heer	x	x	–
Gleditschia allemanica Heer	x	–	–
Gleditschia ovalifolia Heer	–	x	–
Hedera Endoi Morita	x	–	–
Ilex latifolia Thunberg	x	x	–
I. rotunda Thunberg	x	–	–
I. sp.	x	–	–
Juglandiphyllum sp.	–	–	x
Juglans nigella Heer	x	–	–
J. cf. *acuminata* Al. Braun	x	x	–
Leguminosites sp.	–	x	–
L. Brunneri Heer	–	x	–
Liquidambar formosana Hance	x	x	x
Lindera sp.	–	x	–
Laurus nobilis Linné	x	x	–
L. princeps Heer	x	–	–
L. plutonia Heer	x	–	–
L. californica Lesquereux	x	x	–
L. cf. *agathophyllum* Unger	x	–	–
L. protodaphne Weber	x	x	–
Magnolia angustifolia Newberry	x	–	–
Machaerium secundiflorum Morita	x	–	–
Mallotus n. sp.	x	–	–
Persea Braunii Heer	x	–	–
P. cf. *speciosa* Heer	x	–	–
P. sp.	x	–	–
Pittosporum boniense Koidzumi	–	x	–
Pithecolobium sp.	x	–	–
Pyrus sp.	x	x	–
Prunus cf. *pyrifolia* Weber	x	–	–
Protea lingulata Weber	x	–	–
Quercus kazanski Kryshtofovich	–	x	–
Q. praegilva Kryshtofovich	–	x	–
Q. cf. *elaena* Unger	x	–	–
Q. glandulifera Blume	x	x	–
Q. minutus Morita	x	x	–
Q. simulata Knowlton	x	x	–
Q. glauca Thunberg	x	x	–
Q. acuta Thunberg	x	–	x
Q. crispula Blume	–	x	–
Q. sp.	–	x	–
Q. myrsinaefolia Blume	–	x	–
Q. Nathorstii Kryshtofovich	–	x	–
Rhamnus sp.	–	x	–
Rhodendron Kaempferi Planchon	x	–	–
R. sp.	x	x	–
Sapium japonicum Pax et Hoffmann	x	x	–
Sapindiphyllum dubium Nathorst	–	x	–
Sapindus cf. *moskenbergensis* Ettingshausen	x	–	–
Salix tenera Al. Braun	–	x	–
S. integra Goeppert	–	x	–
S. varians Goeppert	–	x	–
S. denticulata Heer	x	–	–
S. viminalis Linné	x	–	–
S. angusta Al. Braun	x	–	–
S. elongata Weber	x	–	–

Fossil Plants from the Basal Miocene of Oguni, Kannonzawa, and Daigo—*Continued*

	OGUNI	KANNONZAWA	DAIGO
S. lavateri Heer	–	–	x
Smilax trinervis Morita	x	–	–
S. minor Morita	x	–	–
Sophora sp.	x	–	–
Sorbus sp.	x	–	–
Trapa yokoyamae Nathorst	–	x	–
T. borealis Heer	–	x	–
Terminalia japonica Morita	x	–	–
Thea japonica Nois. var. Kryshtofovich	–	x	–
Ulmus carpinoides Goeppert	x	–	–
U. sp.	–	x	–
U. longifolia Unger	–	–	x
Viburnum sp.	x	x	–
Vitis sp.	–	x	–
Zizyphus cf. *vulgaris* Lamarck	x	–	–
Z. tiliaefolius Unger	x	–	x
Z. sp.	x	x	–
Phyllites sp.	–	x	–

Fossil Plants from the Miocene of Sirakawa and Hiramaki

	SIRAKAWA	HIRAMAKI
Astraeus sp.	x	–
Equisetum arcticum Heer	x	–
E. sp.	x	–
Lastraea cf. *Valdensis* Heer	x	–
Osmunda sp.	x	–
Woodwardia cf. *japonica* Swartz	x	–
W. sp.	x	–
Glyptostrobus sp.	x	–
Keteleeria sp.	x	–
Pinus sp.	x	x
Sequoia japonica Endô	x	x
Taxodium disticum miocenum Heer	x	–
Taxus sp.	x	–
Cyperites sp.	x	x
Palmoxylon sp.	x	–
Sasa sp.	–	x
Smilax trinervis Morita	x	–
Trachycarpus sp.	x	–
Acer Nordenskiöldi Nathorst	x	–
A. pictum Thunberg	x	–
A. sinense Pax	–	x
A. truncatum Bunge	x	x
A. aff. *trilobatum* Heer	x	–
A. sp.	x	x
A. sp.	x	–
Aralia Yabei Morita	x	–
A. sp.	x	x
A. sp.	x	–
Carpinus grandis Unger	x	–
C. sp.	x	x
C. sp.	x	–
Castanea Kubinyi Kovats	x	–
C. sp.	x	–
C. Ungeri Heer	–	x
Cinnamomum camphora Nees et Ebermaier	x	–
C. lanceolatum Unger	x	–
C. sp.	x	–
C. ? sp.	x	–
Cocculus trilobus D. C. Miquel	x	–
Comptoniphyllum Naumanni Nathorst	x	–
Cornus controversa Hemsley	x	–
Corylus sp.	–	x
Crataegus sp.	–	x
Diervilla sp.	x	x
Diospyros sp.	x	–

Fossil Plants from the Miocene of Sirakawa and Hiramaki.—*Continued*

	SIRAKAWA	HIRAMAKI
Dryophyllum sp.	x	–
Fagus Antipofii Heer	x	–
F. ferruginea Aiton	–	x
E. ? sp.	x	–
Ficus sp.	x	x
Hamamelis japonica Siebold et Zuccarini	x	x
Hedera miocenica Morita MS. nom.	x	–
H. deltoidea Morita MS. nom.	x	–
Ilex sp.	x	–
Lindera citriodora Hemsley	–	x
Liquidambar formosana Hance	x	x
Liriodendron honsyûensis Endô	–	x
Magnolia obovata Thunberg	x	–
M. sp.	x	–
Macclintockia sp.	x	–
Mallotus n. sp.	x	–
Myrica sp.	x	–
Nerium sp.	x	–
Planera sp.	x	–
P. Ungeri Kovats	–	x
Platanus ? sp.	–	x
Quercus alba Linné	x	–
Q. crispula Blume	x	–
Q. glauca Thunberg	x	–
Q. lyelli Heer	x	–
Q. sp.	x	x
Q. sp.	x	–
Rhamnus ? sp.	x	–
Robinia sp.	x	–
Sapium japonicum Pax et Hoffmann	x	–
S. sp.	x	–
Salix lavateri Heer	x	–
S. varians Goeppert	x	–
S. sp.	x	x
S. sp.	x	–
Sassafras variifolium Kuntze	x	–
S. sp.	x	–
Sorbus sp.	x	–
Styrax japonica ? Siebold et Zuccarini	x	–
Tilia sp.	x	–
Ulmus Braunii Heer	–	x
U. longifolia Unger	x	x
U. sp.	x	–
Viburnum sp.	–	x
Vitis sp.	x	–
Zelkowa serrata Makino	x	–

The Palaeogene Ōtuzi coal-bearing group of Kyûsyû is overlain by the marine Asiya group and then by the youngest Sasebo coal-bearing group. The Sasebo group was once thought to be Oligocene in age from its mammalian remains (*Brachyodus*), but its flora is younger in aspect, having *Sequoia japonica* Endô, *Quercus* sp., which is most common, and *Salix longa* Al. Braun. The approximate contemporaneity of the florule to that of the Miocene of Honsyû (cited above) and of Tyôsen (to be cited below) seems very probable.

The Palaeogene coal-bearing group of Kokangen and Agoti, both in Kankyô-hoku-dô on the east coast region of Tyôsen, possess a flora similar to the "Arctic Miocene flora." The older Miocene deposit rests unconformably on the Palaeogene sediments and is marine in its lower part and coal-bearing in its upper. The latter has a flora of an intermediate composition between the Dui-Esutoru flora on the one hand and the Oguni-Kannonzawa flora on the other, and is particularly rich in leaves of evergreen oaks.

It is interesting to note that the remains of *Sequoia* are very common in the Palaeogene floras of Hokkaidô and Kyûsyû, very scanty in the Miocene flora of Honsyû, and again very common in the Pliocene Umoregi (lignite) flora of Honsyû. Endô distinguished, in a study of cones, *Sequoia chinensis* and several other species from the Palaeogene, and from *S. japonica* of the Neogene. In the lignite beds, *Taxodioxylon sequoianum* Gothan is the common wood.

Fagus is another genus the remains of which are often found in profusion in Cenozoic deposits. Especially are the majority of the specimens from the Palaeogene similar to *F. Antipofii* Heer, and this type continued to live to the lower Miocene. One of the living species, *F. crenata* Blume, which first appeared near the end of the Miocene, gradually became more common throughout Pliocene and Pleistocene times; an extinct type allied to *F. americana* Sweet, and usually recorded under the name of *F. ferruginea* Aiton after Nathorst, is almost entirely confined to the Pliocene in distribution, while another living species, *F. japonica* Maximowicz, is very characteristic in the Pliocene and Pleistocene ages. Cases similar to *Fagus* are also found in many other plant genera.

The representative terrestrial deposits of the Pliocene age are the well-known lignite formations, widespread not only in northeastern Honsyû (distributed in the prefectures of Iwate, Yamagata, Miyagi, and Hukusima), but also extended into central Honsyû (Gihu and Aiti prefectures). The majority of the woods of these lignite formations was supplied by a redwood ally, *Taxodioxylon sequoianum* Gothan and a small fractional part by the alder, *Alnoxylon*. The common plants distinguished by their leaves, fruits, and cones from these lignite formations, and other deposits which are either in close stratigraphical position or relation or believed to be almost contemporaneous with them, are listed below. This particular epoch of lignite formation is characterized palaeobotanically by the prevalence of *Sequoia*, as well as the existence of several genera and species, both exotic to present-day Japan, such as *Glyptostrobus*, *Keteleeria*, and *Juglans cinerea* Linné. Further, there are either now living in Japan or at least very closely allied to them a good many species occurring in these lignite formations or corresponding deposits.

Fossil Plants from the Pliocene of Hanamaki (mostly after S. Miki), Sendai, and Akasi (mostly after S. Miki)

	HANAMAKI	SENDAI	AKASI
Abies cf. *balsamea* Miller	–	x	–
A. firma Siebold et Zuccarini	–	–	x
Glyptostrobus europaeus Heer	–	x	–
Picea polita Carrière	–	–	x
Pinus parviflora Siebold et Zuccarini	–	–	x
P. sp.	–	–	x
Sequoia japonica Endô	–	x	x
Thuja japonica Maximowicz	–	–	x
Carex sp.	–	–	x
Moliniopsis japonica Hayata	–	–	x
Sasa borealis Makino et Shibata	–	x	–
S. sp.	–	–	x
Acer Nordenskiöldi Nathorst	x	x	x
A. rufinerve Siebold et Zuccarini	–	–	x
Alnus japonica Siebold et Zuccarini	x	x	x
Ampelopsis brevipedunculata Koehne	–	–	x
Aralia elata Seemann	–	–	x
Berberis longispinus Miki	–	–	x
Berchemia racemosa Siebold et Zuccarini	–	–	x
Betula carpinifolia Siebold et Zuccarini	–	–	x
Buxus japonica J. Müller	–	–	x
Carya akashiana Miki	–	x	–
Cinnamomum Scheuchzeri Heer	–	x	–

Fossil Plants from the Pliocene of Hanamaki (mostly after S. Miki), Sendai, and Akasi (mostly after S. Miki)—*Continued*

	HANAMAKI	SENDAI	AKASI
Distylium racemosum Siebold et Zuccarini	–	–	x
Elaeagnus akashiensis Miki	–	–	x
Euryale akashiensis Miki	–	–	x
Fagara ailanthoides Engler	–	–	x
Fagus crenata Blume	–	x	x
F. microcarpa Miki	–	–	x
Gleditschia japonica Miquel	x	–	x
Humulus japonicus Siebold et Zuccarini	–	–	x
Ilex cornuta Lindley et Paxton	–	–	x
Juglans cinerea Linné	x	x	x
Magnolia obovata Thunberg	–	–	x
M. Kobus A. P. De Candolle	x	–	x
Melia Azedarachi Linné	–	–	x
Nuphar akashiensis Miki	–	–	x
Paliurus nipponicus Miki	x	–	x
Parabenzoin trilobum Nakai	–	–	x
Phellodendron amurense Ruprecht	–	–	x
Prunus Haussknechti Schneider	x	–	–
P. cf. *siberica* Linné	–	–	x
P. cf. *triloba* Maximowicz	–	–	x
Pterocarya stenoptera A. P. De Candolle	–	–	x
Pyrus cf. *Wilhelmi* Schneider	x	–	–
Rosa akashiensis Miki	–	–	x
R. polyantha Siebold et Zuccarini	–	–	x
R. sp.	x	–	–
Salix amygdalina Linné var.	–	–	x
S. gracilistyla Miquel	–	–	x
Sapium sebiferum Roxburgh var.	–	–	x
Staphylea Bumalda A. P. De Candolle	–	–	x
Stauntonia hexaphylla A. P. De Candolle	–	–	x
Stuartia monodelpha Siebold et Zuccarini	x	–	x
S. pseudocammellia Maximowicz	–	–	x
Styrax japonicum Siebold et Zuccarini	x	–	x
S. obassia Siebold et Zuccarini	x	–	x
S. shiraiana Makino	–	–	x
Symplocos crataegoides Miquel	–	–	x
Trapa incisa Siebold et Zuccarini	–	–	x
Ulmus parvifolia Jacquin	–	–	x
Viscum coloratum Nakai	–	–	x
Vitis cf. *flexuosa* Thunberg	–	–	x
V. sp.	x	–	x
Wistaria floribunda A. P. De Candolle	–	–	x
Xanthoceras sorbifolia Bigelow	–	–	x
Zelkova Ungeri Kovats	–	–	x

Probably somewhat younger than the lignite formations above cited is the Mogi flora of Mogi near Nagasaki, famous for its having been discovered by a party of the *Vega* Expedition under the leadership of A. E. Nodenskiöld. The Mogi flora, which comprises, according to Nathorst and Florin, more than 70 species, mostly of dicotyledons, is particularly rich in the leaves of *Fagus americana* Sweet, which is now living in the Atlantic region of North America. In this connection it must be remembered that the fossil leaves are almost indistinguishable from those of *F. ferruginea* forma *rosthornii* figured by Ettingshausen on the specimens from Ssuchuan, China, and therefore this type of fossil leaves may point to an affinity of the Mogi flora to the recent vegetation of China rather than to that of the Atlantic region of North America. According to the two Swedish authorities, there is one more Atlantic North American element, *Taxodium distichum* Richard, besides a Himalayan element, *Rhus* Griffithii Hooker, in the fossil flora; however, the former material is too scanty and fragmental for precise determination. More than half of its constituents (52 per cent, according to Florin) is now extinct on the island, and although the percentage may fluctuate about this figure in later studies, the Upper Pliocene age of the fossil flora is convincing from geological and palaeobotanical evidences.

Nathorst pointed out that the Mogi flora is a mountain flora grown under a condition certainly colder than the present-day climate of the district, and has a constitution quite analogous to the recent vegetation of the belt of *Fagus crenata* in the sense of J. Tanaka, which, according to him, now lies in an altitude above 800 m. in the region, while the present position of the plant beds is near sea level. Lately G. Koidzumi, in comparing it with the recent vegetation of Unzendake near by, found its similarity to be in the mountain flora of some 1000 m. or a little less in altitude.

FOSSIL PLANTS FROM MOGI (after R. Florin)

- (?) *Taxodium distichum* Richard
- *Acanthopanax acerifolium* Nathorst
- *Acer pictum* Thunberg
- *Betula* (?) sp.
- *Carpinus stenophylla* Nathorst
- *Celtis Nordenskiöldi* Nathorst
- *Clethra Maximowiczi* Nathorst
- *Cydonia chloranthoides* Nathorst
- *Dictamnus albus* Linné
- *Elaeocarpus photinaefolia* Hooker et Arnott
- *Fagus ferruginea* Aiton
- *Juglans Sieboldiana* Maximowicz
- *Lindera sericea* Blume
- *Liquidambar formosana* Hance
- *Magnolia* sp.
- *Ostrya virginica* Willdenow
- *Phyllites acuminatus* Nathorst
- *Phyllites angustus* Nathorst
- *Phyllites caryoides* Nathorst
- *Phyllies crenatus* Nathorst
- *Phyllites inaequabilis* Nathorst
- *Phyllites myricoides* Nathorst
- *Phyllites ovatus* Nathorst
- *Prunus Buergeriana* Miquel
- *Quercus Stuxbergi* Nathorst
- *Rhus Engleri* Nathorst
- *Salix* (?) sp.
- *Sophora* (?) *fallax* Nathorst
- *Stuartia monodelpha* Siebold et Zuccarini
- *Styrax obassia* Siebold et Zuccarini
- *Tilia* sp.
- *Tripetaleia Almqvisti* Nathorst
- *Ulmus* cf. *carpinoides* Goeppert
- *Vaccinum* (?) *saportanum* Nathorst
- *Vitis labrusca* Linné
- *Zelkova keaki* Siebold
- *Phyllites bambusoides* Nathorst
- *Acer Nordenskiöldi* Nathorst
- *Acer* sp.
- *Carpinus subcordata* Nathorst
- *Carpinus* sp.
- *Clematis Sibiriakofii* Nathorst
- *Cornus* sp.
- *Deutzia scabra* Thunberg
- *Diospyros Nordqvisti* Nathorst
- *Excoecaria japonica* J. Müller
- *Ilex Heeri* Nathorst
- *Juglans Kjellmani* Nathorst
- *Lindera* (?) sp.
- *Magnolia Dicksoniana* Nathorst
- *Meliosma myriantha* Siebold et Zuccarini
- *Phyllodendron amurense* Ruprecht
- *Phyllites ailanthoidea* Nathorst
- *Phyllites attenuatus* Nathorst
- *Phyllites cissoides* Nathorst
- *Phyllies fraxinoides* Nathorst
- *Phyllites minutus* Nathorst
- *Phyllites obsoletus* Nathorst
- *Phyllites pusillus* Nathorst
- *Prunus pseudo-cerasus* Lindley
- *Rhus Griffithii* Hooker fil.
- *Salix* sp.
- *Schizandra chinensis* (Ruprecht) Baillon
- *Sorbus Lesquereuxi* Nathorst
- *Styrax japonicum* Siebold et Zuccarini
- *Tilia distans* Nathorst
- *Tilia* sp.
- *Ulmus* cf. *campestris* Smith
- *Ulmus* sp.
- *Viburnum erosum* Thunberg
- *Xanthoxylum ailanthoides* Siebold et Zuccarini
- *Zizyphus* sp.

Pleistocene plant beds occur at numerous localities in various parts of the Japanese Islands, and as the best example of the Pleistocene flora the Siobara flora of Siobara, Totigi Prefecture, not far distant from Nikkô, can be here cited. The plant beds, which are lake deposits at the northern foot of the Takahara volcano, contain a rich flora, comprising some 120 species as listed below. It is a mountain flora with a great many species belonging to the families *Betulaceae, Aceraceae,* and *Fagaceae.* About 90 per cent of its species are still living in Japan, most of them being common trees of the present temperate and frigid zones, and a few exist only in the frigid zone. *Carpinus cordata* Blume, *C. japonica* Blume, *Castanea crenata* Siebold et Zuccarini, *Clethra barbinervis* Siebold et Zuccarini, *Cornus controversa*

Hemsley, *C. Kousa* Buerger, *Maackia amurensis* Ruprecht, *Magnolia obovata* Thunberg, *Rhododendron dilatatum* Miquel, and *Stewartia pseudo-Camellia* Maximowicz are now living in the temperate and warm temperature forest zone, but there is none which habitates in the warm temperature zone only. The living representatives of the fossil flora are quite similar to or almost the same species as those found in the present flora of central Hokkaidô. At the present time the difference in mean temperature between Utunomiya, near Siobara, in central Japan, and Sapporo, in central Hokkaidô, is about 6° C. Living representatives of these fossil species now exist in the high mountains of central Japan, and the altitude of their most luxuriant growth is about 1500 m., while the present altitude of the plant beds is some 500 m.; the past altitude of the lake when its deposits were being formed is assumed to be 500 to 600 m. The difference in altitude, therefore, between the present day and the Pleistocene age, when there was luxuriant growth, would be about 900 to 1000 m. The list follows.

FOSSIL PLANTS FROM SIOBARA, TOTIGI PREFECTURE

Aspidium sp.
Dryopteris Miqueliana C. Christensen
Woodsia polystichoides Eaton
Abies Mariesii Masters
Picea sp. ?
Pinus pumila Regel ?
Thuja standishii Carrière
Acer carpinifolium Siebold et Zuccarini
Acer diabolicum Blume
Acer euseptenlobum Koidzumi
Acer micranthum Siebold et Zuccarini
Acer Nodenskiöldi Nathorst
Acer pictum Thunberg
Acer Sieboldianum Miquel
Acer ? sp.
Alnus hirsuta Turczaninow
Alnus pendula Matsumura
Araliphyllum Naumanni Nathorst
Betula grossa Siebold et Zuccarini
Betula latifolia Komarov
Betula Schmidtii Regel
Betula sp.
Carpinus carpinoides Makino
Celtis Bungeana Blume var. *jessoensis* Miyabe et Kudo
Cercidiphyllum japonicum Siebold et Zuccarini
Clematis apiifolia A. P. De Candolle
Cornus controversa Hemsley
Cynoxylon japonica Nakai
Fagus japonica Maximowicz
Hamamelis japonica Siebold et Zuccarini
Hydrangea hirta Siebold et Zuccarini
Ilex geniculata Maximowicz
Juglans sp.
Maackia amurensis Ruprecht et Maximowicz
Magnolia obovata Thunberg
Malus Zumi Matsumura
Meliosoma myriantha Siebold et Zuccarini
Micromeles japonica Koehne
Myrophyllum sp.
Phellodendron amurense Ruprecht
Prunus Maximowiczii Ruprecht
Pterocarya sp.
Quercus acutissima Carrière
Ranunculus aquatilis Linné
Rhododendron degronianum Carrière f. *spontaneum* Nakai
Rhodendron dilatatum Miquel
Rhodendron glabrius Nakai
Salix sp.
Sorbus gracilis C. Koch
Sorbus commixta Hedlund
Stewartia pseudo-Camellia Maximowicz
Tilia distans Nathorst
Tilia japonica Simonk
Tripetaleia bracteata Maximowicz
Trochodendron araliodes Siebold et Zuccarini var. *longifolium* Maximowicz
Ulmus propinqua Koidzumi
Viburnum furcatum Blume
Vitis flexuosa Thunberg
Davallia bullata Wallich
Dryopteris sp.
Woodsia manchuriensis Hooker
Taxus cuspidata Siebold et Zuccarini
Pinus pentaphylla Mayr
Tsuga diversifolia Maximowicz
Sasa borealis Makino et Shibata ?
Acer crataegifolium Siebold et Zuccarini
Acer eupalmatum Koidzumi
Acer japonicum Thunberg
Acer Miyabei Maximowicz
Acer nikoense Maximowicz
Acer rufinerve Siebold et Zuccarini
Acer Tschonoskii Maximowicz
Actinidia polygama Maximowicz
Alnus Maximowiczii Callier
Amelanchier asiatica Endlicher
Berchemia racemosa Siebold et Zuccarini
Betula Ermani Chamisso
Betula Maximowicziana Regel
Betula sollennis Koidzumi
Carpinus cordata Blume
Castanea crenata Siebold et Zuccarini
Ceridiphyllum magnificum Nakai
Clethra barvinervis Siebold et Zuccarini
Crataegus sp.
Fagus crenata Blume
Fraxinus longicuspis Siebold et Zuccarini
Hedera ? sp.
Hydrangea paniculata Siebold

Fossil Plants from Siobara, Totigi Prefecture—*Continued*

Juglans Sieboldiana Maximowicz
Kalopanax septemlobum Koidzumi
Magnolia sp.
Meisteria campunulata Nakai
Micromeles alnifolia Koehne
Myriophyllum spicatum Linné
Palura paniculata Nakai
Phyllites 8 spp.
Prunus sp.
Quercus crispula Blume
Ranunculus acris var. *japonica* Maximowicz
Rhamnus sp.
Rhodendron Kaempferi Planchon
Rhododendron 2 spp.
Schizophragma hydrangeoides Siebold et Zuccarini
Sorbus sp.
Sorbus rufo-ferruginea Koidzumi
Styrax obassia Siebold et Zuccarini
Tilia Miyabei Jackson
Tilia sp.
Tripetaleia paniculata Siebold et Zuccarini
Viburnum urceolatum Siebold et Zuccarini
Viburnum Wrightii Miquel
Xolisma elliptica Nakai

Finally, a recent, interesting discovery of S. Miki's may be cited. In a clay bed underlying the Younger Pleistocene Kwantô loam at Ekoda, Nakano district, Tokyô, the Ekoda conifer bed, as he called it, has a flora of which the dominant types are: *Abies Mariesii* Masters, *Larix Kaempferi* Sargent, *Picea hondoensis* Mayr, and *Pinus koraiensis* Siebold et Zuccarini. These conifers are now growing at a height above 1300 m. in the adjacent Kwantô mountain land. This fossil occurrence requires special explanation as the localities are on the Kwantô platform, and only 37 m. above the present sea level. Miki believes that the land had a considerable height during the deposition of the conifer bed. Perhaps many other physical conditions must be taken into consideration before conclusions are fairly to be drawn.

HISTORY OF VERTEBRATE PALEONTOLOGY ON THE WEST COAST

By Charles L. Camp

Limitation of space requires extreme condensation of this subject; consequently much important work must be omitted or only briefly mentioned.

The Spanish period in the Southwest saw but little in the way of scientific activity. It did witness, however, the discovery of vertebrate fossils in Western America. José Martínez, a Spanish botanist, visited the death trap at Rancho La Brea in 1792. He described the locality in some detail (translation by Lesley B. Simpson) : "Farther to the west of the Pueblo de Los Angeles there are more than twenty springs of liquid petroleum, pitch, etc. . . . In the middle of a great plain of more than fifteen leagues in circumference there is a great lake of pitch, with many pools in which bubbles or blisters are continually forming and exploding. They are shaped like conical bells and when they burst at their apex they make a little report.

"The variety of the great masses of tar, the movement which one sees in all of them at once, the pitchy smell, the sight of that great lake of strange matter, and the phenomena, present an astonishing and frightful aspect, reminding one of pictures painted of the infernal caverns. If one stands upon the more solid masses of pitch, one seems to be ascending from the ground. The plain of pitch upon which one stands sinks in the form of a cone, with the point downward. In hot weather animals have been seen to sink in it and when they tried to escape were unable to do so, because their feet stuck and the lake swallowed them. After many years their bones have come up through the holes, as if petrified. I have brought away several specimens."

Martínez had a museum of his own in Mexico City at that time. The locality lay fallow for nearly one hundred years.

The pioneer American period in the West began with the trappers who frequently saw fossils but seldom collected them. Government exploring expeditions such as those of Wilkes and Frémont collected specimens and made geological notes. Most of Frémont's specimens of the 1844 expedition were destroyed by a flood in Kansas. The remainder, a few fossil leaves and shells, were studied by James Hall and published in the brief "Appendix B" of Frémont's 1845 report. No fossil vertebrates are mentioned.

In the early 1800's a few of the foreign voyagers to the West Coast made geological observations. The most important of them was Beechey, who surveyed San Francisco Bay and in 1830 published a colored geological map of its shores. The pre-Gold Rush American immigrants to California had but little to say of fossils. A petrified whale skeleton on a mountaintop near Livermore is mentioned in some of the narratives.

Geological studies in the West owe their inception to the Gold Rush. The California Academy of Sciences, founded in 1853, counted among its members such men as J. B. Trask and W. P. Blake, who devoted themselves to research and publication and encouraged the scientific organization of the Railroad Surveys from 1853 to 1855.

The geological reports of the Railroad Surveys were written up by Newberry, Evans, Antisell, Marcou, and by Blake himself, whose *Report of a Geological Reconnaissance in California* comprises the fifth volume of the series, 1857. Louis Agassiz described in this report a number of shark teeth collected by Blake's party, principally on Poso Creek in Kern County and at Navy Point near Benicia. Only the most general age determinations are given, but Agassiz's report in the *American Journal of Science*, 1856, is apparently the first formal description of fossil vertebrates from the Coast.

Blake noted proboscidian remains in the auriferous drift, as he called it; but he did not notice these bones above that level, so he believed that since the marine strata containing Miocene fossils were free from gold, the "impregnation of the rocks with gold and the formation of the coast mountains were nearly synchronous." Negative evidence from the vertebrates led him to suppose that the postauriferous deposits "were more recent than the Mammoth and the Mastodon." All this was erroneous.

The Geological Survey of California was an official scheme authorized by the Legislature in 1860, with Josiah Dwight Whitney of Harvard in charge. William M. Gabb of Yale was the paleontologist. He and Fielding Bradford Meek worked up the results, one volume of which was published in 1864. Only one lot of invertebrates was described. The vertebrates, a few of which were collected by various members of the party and some of which came in by gifts from miners and others, were turned over to Dr. Joseph Leidy of Philadelphia and described by him in the *Proceedings* of the Academy of Natural Science, Philadelphia, 1865–1868. *Equus occidentalis, Bison antiquus, Elotherium superbum,* and the ichthyosaur, *Cymbospondylus,* from Nevada were among the new forms. Brewer and Whitney, in the *American Journal of Science,* published notices of the famous Calaveras skull, elaborated by Whitney in 1880 in his famous memoir on the auriferous gravels, for which Leidy wrote the other vertebrate descriptions. The work was issued by the Museum of Comparative Zoölogy at Harvard and is the first successful attempt on the West Coast to employ vertebrate fossils in stratigraphy, age determinations, and correlation. The so-called infusoria and the plants were also treated in this account. The remains were scanty and fragmentary, so, even though comparisons were attempted with Condon's Oregon discoveries and with one or two of the plains faunas, it is more important as a forerunner of modern methods than in the soundness of its conclusions.

A number of specimens from the gravels had been collected by the miners, who had burrowed through the hills in every direction. Even the extensive hydraulicking operations had failed to uncover complete skeletons or even skulls. The only exception was the skeleton of a mammoth uncovered but not collected from near Millerton in Fresno County. This lack of skeletons seemed very strange to Whitney, but subsequent explorations have not until recently brought to light much additional material and this more recent material has come largely from the Pliocene andesitic tuffs.

Mammoth, mastodon, and horse remains were the most abundant, in the order named. Probably hundreds of the former were dug up. Most of them were carried off as souvenirs and some found their way into saloons and stores, where they were displayed for a time.

Whitney noticed that remains of the mammoth, or elephant, as he called it, were never found in some of the older beds where mastodon occurred, and that they were not found under the basalt flows capping the gravels. He also noticed that "no traces of the rhinoceros, the elotherium or the small equine animal referred with doubt, by Leidy to *Merychippus* [really *Hipparion*] have been found in deposits which could by any possibility be proved to be more recent than the basaltic overflow." His opinion then was that the prebasalt deposits were of Miocene rather than of Pliocene age. Lesquéreux's identifications of the plants strengthened him in these conclusions.

According to R. A. Stirton, Whitney's rhino and *Elotherium* probably came from pre-Pliocene beds and his so-called *Merychippus* may be referable to a small early Pliocene *Hipparion.*

Whitney's ideas of the antiquity of man, namely, "Man, thus far, is nothing but Man, whether found in Pliocene, Post-Pliocene, or Recent formations," were erroneous because of his mistaken view concerning the age and occurrence of the Calaveras skull.

Those who may be interested in the survey and the localities visited will find Brewer's letters, edited by Francis Farquhar, very full and vivid; *Up and Down California* is the title.

During the 60's, 70's, and 80's amateur collectors such as Dr. Thomas Condon of Oregon and Lorenzo G. Yates of Santa Barbara made important vertebrate discoveries. Condon brought the John Day beds to the attention of the scientific world. Yates sent some of his material to Cope and Leidy. Dr. O. C. Marsh procured from him the type tooth of *Desmostylus*—a sea-cow-like marine mammal whose relationships have only lately been worked out. Marsh visited California in 1880 and did but little collecting. Cope came in 1879 and from that time until his death he published some thirteen papers on the vertebrates of California, Nevada, and Oregon. He visited the McCloud River and published the first descriptions of Pleistocene fossils from the Shasta Caves. He also made the first collections at Fossil Lake, Oregon, and was the first to really study the Carson footprints.

Joseph LeConte, despite his long-continued interest in the geology of the West, published practically nothing on vertebrate fossils. The only paper known to me is a brief note on the Carson footprints in *Nature*, 1883. LeConte, however, attracted John C. Merriam to the University of California and nothing could have been more propitious for the future of paleontology in the West.

Merriam's field work and publications began in the early 90's. His first notice of the Shasta Triassic ichthyosaurs, brought to his attention by James Perrin Smith, appeared in 1895. The next year, fossils were noted in the Orinda Pliocene of the Berkeley Hills, and in rapid succession new fields were discovered and prospected in the California and Nevada Tertiary and Pleistocene, and in the Triassic of Idaho and Nevada. The tar pits at Rancho La Brea and McKittrick as well as the Barstow Miocene, Virgin Valley, and Thousand Creek, the great sequence in central Oregon, Hawver Cave, the Shasta Caves, the Ricardo, the Chanac, and the Etchegoin and Jacalitos, received their first serious study by Merriam and his students. In the Coalinga region Merriam was able to tie-in the vertebrate continental sequence with the marine formations. His work on the Triassic ichthyosaurs elucidates the morphology of those primitive forms, and the remarkable completeness of his material enabled him to make important comparisons with similar forms in Spitzbergen and Italy. His work in the John Day was used by Osborn and Matthew in filling large gaps in the North American stratigraphic sequence.

Throughout the progress of his work Merriam was supported by funds contributed by Miss Annie M. Alexander, who, with Miss Louise Kellogg, went into the field year after year and made very important discoveries, particularly in the Barstow region, which has been extensively worked in later years by Childs Frick, a private collector of New York. Merriam's students, Sinclair of Princeton, Stock, Buwalda, Pack, C. L. Moody, B. L. Clark, Kew, Packard, Nomland, and others, have become well known for their contributions to geology and paleontology.

William Diller Matthew came to the University of California from the American Museum in 1927. With the support of Miss Alexander and the assistance of R. A. Stirton and V. L. VanderHoof he organized a program of collecting in Texas and the Great Plains in order to compare the classic American sequence, particularly in the Pliocene, with that on the West Coast. This work has been continued by Mr. Stirton since Matthew's death nine years ago.

During the past decade Dr. Chester Stock at the California Institute of

Technology with his group of students has continued much of the work initiated by Dr. Merriam, and has discovered in southern California an Upper Eocene-Oligocene sequence of faunas containing primitive mammals which are comparable with those found in the Rocky Mountain basins. Stock, Loye Miller, Hildegarde Howard, Alden Miller, and others have continued to describe the Rancho La Brea faunas. The Museum of Science at Los Angeles has collected extensively at this locality.

At the University of California the Museum of Paleontology has lately been developing Pliocene quarries in the vicinity of Mount Diablo, at Lafayette, at Knight's Ferry, Tracy, and Rodeo. An interesting Cretaceous fauna consisting of a dinosaur, a plesiosaur, and a mosasaur has been taken from the Moreno formation west of Fresno. This and other work has been carried on with the help of the W.P.A., who have also assisted in the laboratory preparation.

Progress in the West may be divided into three periods: (1) pioneer exploration and surveys, 1792–1870; (2) amateur collecting, 1870–1890; (3) planned scientific work, mostly under university auspices, 1890 to the present. In the third period we believe that there is a growing tendency toward more accurate determinations based on larger quantities of material; more extensive knowledge of whole faunas, with search for, and deep excavation of, rich quarries; and improvements in field and laboratory technique.

The future may expect to see a knowledge of early Tertiary faunas comparable with what we now know of the Pliocene and Pleistocene; also desirable is a much more accurate knowledge of the Pleistocene sequence. Many of our correlation problems have arisen because of inadequacy of determinations and the lumping of stages and faunas in lithologic units. When detailed geological studies are completed and when our faunas become better known, these problems will tend to resolve themselves.

THE MOVEMENTS OF THE FAUNA BETWEEN ASIA AND NORTH AMERICA SINCE THE LOWER CRETACEOUS

By P. Teilhard de Chardin

Between Asia and North America faunal relations are obvious during the Cenozoic, and they have already been analyzed by several paleontologists (see W. D. Matthew's *Climates and Evolution*). What I wish to do here is merely to emphasize a few general characters found in these faunal exchanges which I believe to have a special paleogeographic and paleoclimatic significance.

1. *The characters.*—On the whole, faunal north-circumpacific connections, since the Lower Cretaceous, seem to have been: limited, almost continuous (or at least repeated), spasmodic, selective, and perhaps steadily decreasing.

a) *Limited.* At no time during the Cenozoic were the North American and North Asiatic faunas identical. On the contrary, the differences between both are so deep that no American faunal assemblage can be mistaken, at any time, for an Asiatic one.

b) *Continuous* (or repeated). Nevertheless, at each period, a clear synchronism is observable in the development of the fauna on both sides of the Pacific. Not only are certain orders and families fundamentally the same, but a number of identical genera (or even species) are recognizable. Such similarities do not prove a complete absence of breaking between the two continents, but they require at least repeated geographical intercommunications allowing a periodic faunal readjustment.

c) *Spasmodic.* Either periodically interrupted or not, the intercontinental connections between Asia and North America show a distinct succession of maxima and minima, expressed in major or minor faunal interchanges:

Maxima:

Upper Cretaceous.—Ceratopsid Dinosauria, etc. (←→).[1]
Eocene.—Creodonta, Amblypods, *Titanotherium*, primitive Perissodactyla (←→).
Miocene.—*Hemicyon* (→), *Anchitherium* (←), Mastodontidae (→), etc.
Pontian.—*Hyaenarctos* (→), *Plesiogulo* (→), *Promephitis* (→), *Machairodus* (←→), *Hipparion* (←), Chalicotherids (→), etc.
Villafranchian.—Horse and Camel (←), *Mimomys* (→), *Elephas* (→), probably Ovibovids (→), and Deer (→) etc.
Late Pleistocene.—Reindeer, *Elaphus* Deer, Moose, *Elephas prigenius* (→) . . .

Minima: Oligocene, Middle Pliocene, Early Pleistocene . . .

d) *Selective.* In spite of so many faunal exchanges in the course of the Cenozoic, a remarkable fact is that a number, not only of specialized forms, but of massive groups as well, did not use the continental bridge, even when it was obviously opened: no Oreodontidae, Antilocapridae, Cranioceratidae, *Hyaenognathus*-like Dogs went to Asia; no Giraffidae, Antelopes, Stegodons, Ostrich passed in America. In the case of Oreodontidae, Antilocapridae, etc., it may be said that the *main* development of the group occurred precisely during the minima of intercontinental communications. But in the case of the Pontian Giraffidae, Antelopes, etc., this explanation does not work. Evidently, even at its best, the Cenozoic North Pacific bridge was never a very broad or comfortable one. Like a constricted channel, it yielded only to lucky strokes, or to swift and adaptable animals, or to heavy biological pressures.[2]

e) *Steadily decreasing.* On this last point I do not wish to be positive. Yet as a whole North Pacific land communications seem to have been increasingly difficult from Eocene to Pleistocene time. It may be suggested that the present conditions express, both geographically and (if we except some temporary glacial phases) climatically, an absolute minimum for faunal exchanges between the two continents.

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[1] ←, from America; →, from Asia; ←→, trend of the migration uncertain.

[2] From the facts quoted above, it would seem that, since the Miocene at least, the higher faunal pressures were mainly in Asia.

2. *The interpretation.*—Considering these various facts, one may visualize the Cretaceous and Cenozoic land connections between North Asia and North America as roughly similar to those existing today between North and South America : a narrow, and probably narrowing, strip of land, broad enough to prevent a complete specialization of the American fauna, but at the same time so reduced as to develop a marked differentiation of the partly isolated types. In other words, the present relative position of the two land masses was already foreshadowed and incipient at the end of the Mesozoic.

ADDITIONAL EVIDENCE FOR A HOLARCTIC DISPERSAL OF FLOWERING PLANTS IN THE MESOZOIC ERA

By G. Ledyard Stebbins, Jr.

No botanist can study present-day floras without being struck by the anomalous, disrupted range of many groups of plants, and there is little doubt that such distributions reflect in some way the past history of our floras. Although interpretations of such modern distributions may always be more or less open to question, I believe that they should be pointed out whenever recognized, and that any logical hypothesis to explain their existence is worthy of consideration. With the rapidly increasing knowledge of geology and particularly palaeontology that is now taking place, their significance will undoubtedly become clearer in the future, and a knowledge of them will surely lead to a better understanding of past floras and past climates. I have had the unusual opportunity in recent years of studying intensively at nearly the same time two groups which represent opposite ends of the phylogenetic tree of the flowering plants: the genus *Paeonia,* one of the most primitive of the Ranales, and the tribe Cichorieae, one of the most advanced of the great family Compositae, which is generally recognized as the most highly developed of the Angiosperms. Strangely enough, the anomalous patterns of distribution found in these groups have certain features in common.

In the first place, the Compositae. As was recognized long ago by Bentham (1873, pp. 391–392), this family has a remarkably high proportion of relict genera in view of its high stage of evolution, and of the obviously modern, weedy character of so many of its species. Such relicts are not lacking from the Cichorieae, but they are much more numerous in another tribe, the Mutisieae, which has some characteristics in common with the Cichorieae, and may be remotely related to them. Of the 56 genera of Mutisieae, 30 may be considered relicts; that is, they are small in number of species and either have strikingly disrupted ranges or have relatives in regions remote from those

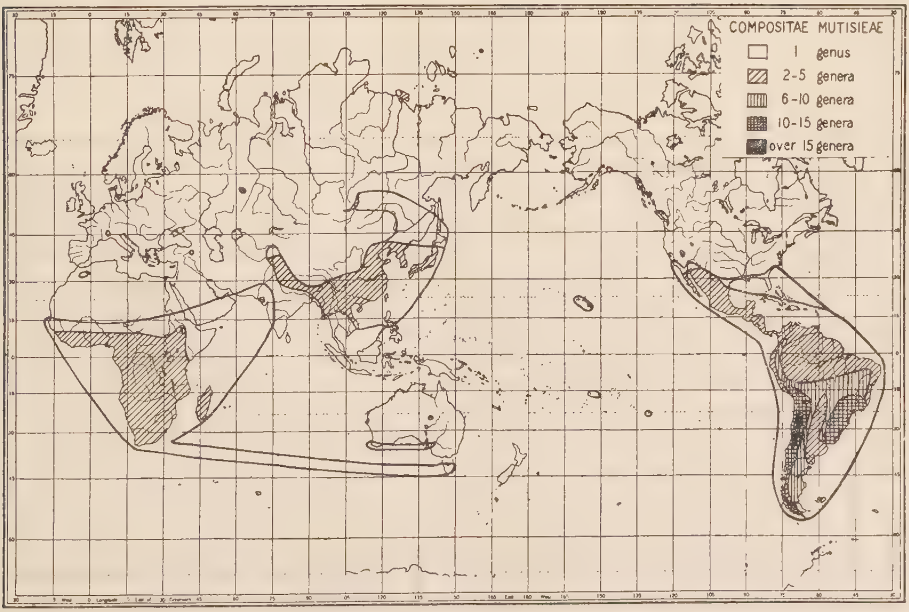

Fig. 1. Distribution of the tribe Mutisieae.

in which they are found. Furthermore, the Mutisieae have the highest proportion of woody genera of any tribe of Compositae, and are the only major tribe which has not produced a single cosmopolitan weed.

The first pattern of distribution to be presented is that of the whole tribe Mutisieae(fig. 1). This has been compiled from Hoffman's (1890) treatment of the tribe in *Die natürliche Pflanzenfamilien,* as well as from a series of regional floras and check lists. It shows as accurately as could be determined the approximate number of genera occurring together in each area. The majority of Mutisieae are now found in the Southern Hemisphere, and their great center of concentration is the southern Andes. Minor centers, which do not show on the map, occur in Mexico, the mountains of China, and tropical and south Africa. The presence of the majority of Mutisieae in the Southern Hemisphere might suggest an antarctic distribution for the tribe, but before any conclusions are drawn on this point the following facts should be noted. In the first place, the tribe is practically absent from all of Australia, New Zealand, and Polynesia. The only endemic Australian species was originally described by Bentham as a distinct genus, but was later reduced by him to the South American genus *Trichocline. Fitchia,* endemic to two islands of Polynesia, is probably best placed in the Mutisieae, but has also been referred to both the Cichorieae and the Heliantheae, and is apparently a nondescript genus which combines the characteristics of all three tribes. Second, there are in the Northern Hemisphere no fewer than five monotypic relict endemic genera or subgenera which occur entirely outside of the range of the tribe as a whole. These are *Hecastocleis* in the western United States, *Hesperomannia* in Hawaii, a subgenus of *Gerbera* in Armenia, *Berardia* in the western Alps, and *Warionia* in the northern Sahara. The third point was suggested to me earlier in these meetings by Professor Andrews (1939) when he said that one should look for the center of origin of a group in the regions where its relatives are found. As Bentham (1873) observed, the tribes most nearly related to the

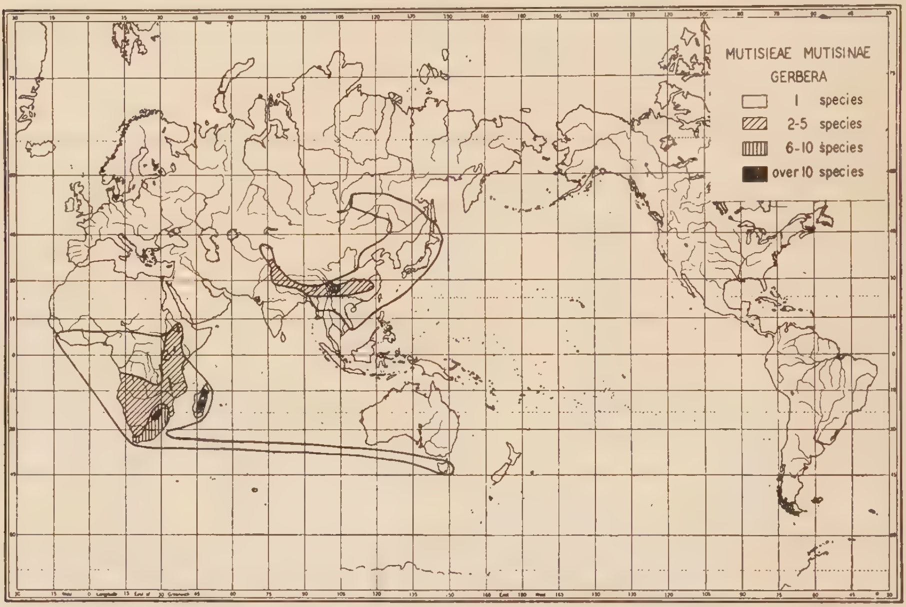

Fig. 2. Distribution of the genus *Gerbera.*

Mutisieae, the Cynareae or thistles and the *Inula* subtribe of the Inuleae, both have their center in the Mediterranean region. In fact, the Mutisieae of South America appear like a large expeditionary force in a foreign country. On the strength of this evidence, we may apply the principle developed by Matthew (1915) and suggest that the original center of distribution of the Mutisieae was in Eurasia, while the present main centers of concentration of species are at the periphery of the former range of the tribe.

Evidence in support of this hypothesis can be found in the distribution of individual genera of the tribe. Most of the African genera of Mutisieae are more or less transitional toward the Cynareae, and this is particularly true of the relict *Berardia* of the Alps. Of the African genera, only *Gerbera* shows a connection with the other regions in which Mutisieae are found. This genus has the widest range of any in the Old World, and has centers of concentration in South Africa, Madagascar, and western China (fig. 2). It thus establishes a clear connection between the African and Asiatic centers for the tribe. Between the Asiatic and South American centers there are definitely recognizable connections. One series is represented by a group of small relict genera which have in common a woody habit, heads containing all perfect, bisexual flowers, zygomorphic corollas, and a style and stigma without "collecting hairs." These are the monotypic *Catamixis* of the northwestern Himalaya, *Nouelia* of Yunnan, *Dinoseris* and *Hyaloseris*, with one and three species respectively, in the Argentine Andes, and *Proustia*, with ten species in the Andes and three in the West Indies (fig. 3). I shall leave it to the specialist on this tribe to decide whether these genera are actually closely related to each other, but some characteristics about them seem to me significant. The ligulate type of corolla, rarely found in the Mutisieae and characteristic of the Cichorieae, occurs in *Catamixis, Dinoseris,* and *Hyaloseris;* while *Nouelia* certainly resembles *Dinoseris* more than any Asiatic genus. *Augusta* (*Stifftia*) of Brazil and *Hesperomannia* of Hawaii also resemble these last two genera, but are placed by

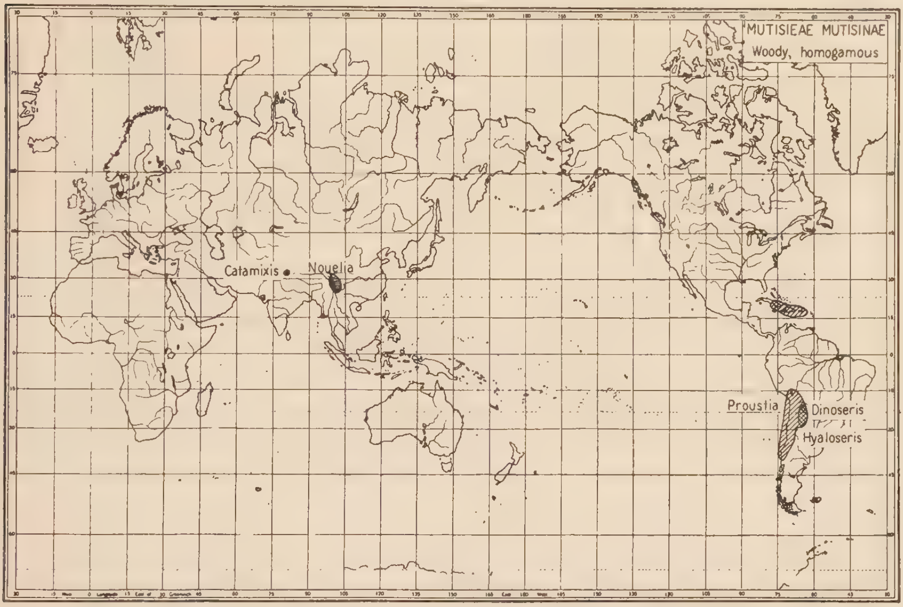

Fig. 3. Distribution of certain genera of Mutisieae.

Hoffmann (1890) in a different subtribe on account of their actinomorphic corollas.

An even closer connection between the Asiatic and American Mutisieae is provided by the twin genera *Gochnatia* and *Leucomeris* (fig. 4). There is no doubt that these two genera are closely related (cf. Bentham, 1873, p. 472), and consideration of all of the species now known may make it necessary to unite them. Particularly significant in this respect is the striking *Gochnatia arborescens* Brandg. of the cape region of Lower California.

If the Mutisieae were a group which originated in and was dispersed from Antarctica, we should expect to find the most definite connections between the centers for the tribe in the Southern Hemisphere, that is, South America and South Africa. Such connections, however, are not evident. Furthermore, we should expect at least a fair representation of Mutisieae or their relatives in Australia and New Zealand. On the contrary, the Compositae of these two land masses belong predominantly to the tribes Astereae, Inuleae, Anthemidae, and Senecionae, show definite relationships to other members of these same tribes found in Africa, South America, Polynesia, and Malaysia, and are not at all related to the Mutisieae.

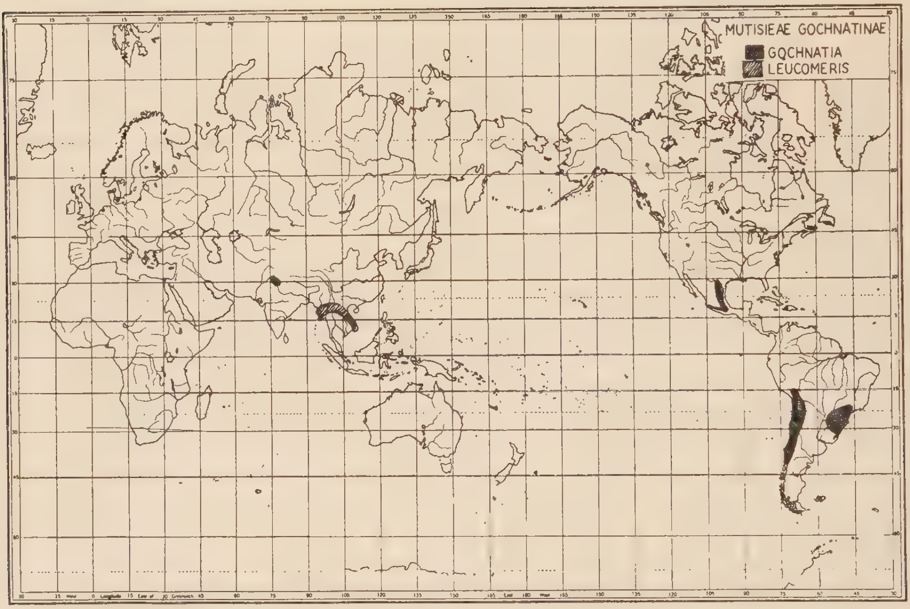

Fig. 4. Distribution of the genera *Gochnatia* and *Leucomeris*.

Turning now to the tribe Cichoriae, we find one genus which has a distribution somewhat similar to that of the Mutisieae, namely *Hypochaeris* (fig. 5). This genus contains 8 species in the Mediterranean region, including the widely naturalized *H. radicata* and *H. glabra*, 2 more in the Alps and northern Eurasia, 1 in northeastern Asia, and 35 or 40 in temperate South America. There is no question that the Eurasian and South American species are congeneric; in fact, the Asiatic *H. grandiflora* is closer to species of northern Chile than to any Old World species. As in the Mutisieae, the majority of *Hypochaeris* species are in the Southern Hemisphere, and in this case the origin of the genus in western Eurasia is as certain as such things can be. The only other Cichorieae in South America are a few isolated representatives or close relatives of North American or Eurasian genera quite different from *Hypochaeris,* while western Eurasia is, on the other hand, the home of a series of flourishing modern genera, such as *Leontodon, Picris, Scorzonera,* and *Crepis,* which are close to *Hypochaeris* and probably at least partly derived from it. The complete absence of native species of *Hypochaeris* from North America is most remarkable, particularly in view of the success that its two European immigrants have had in colonizing this region, and the great climatic similarity between Pacific North America and Chile. Three of our genera, however, *Pinaropappus, Nemoseris* (*Rafinesquia*), and *Microseris,* may be related, though not closely, to it. *Hypochaeris* is an almost perfect example of the type of distributional pattern considered by Matthew (1915) to be characteristic of old genera.

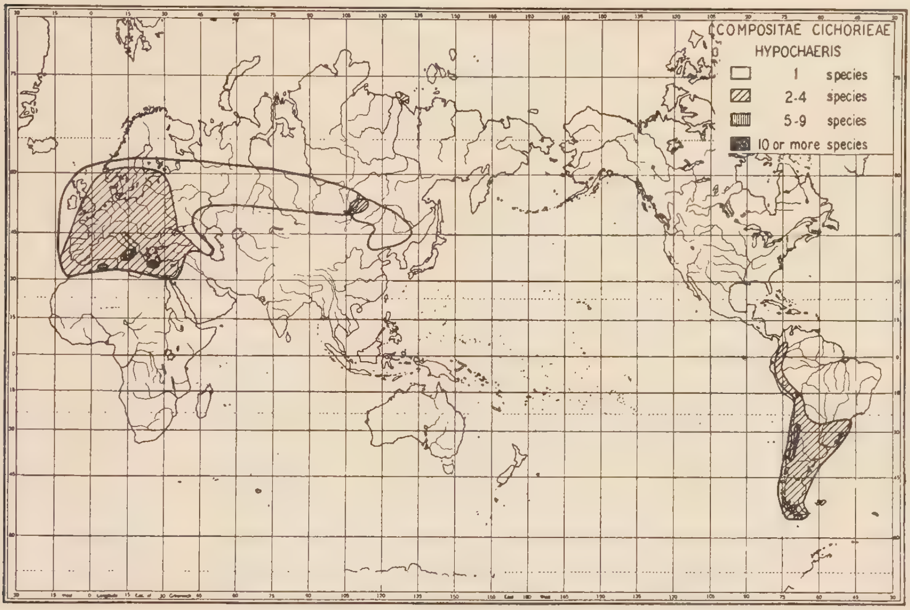

Fig. 5. Distribution of the genus *Hypochaeris.*

There is no good evidence that any genus of either the Mutisieae or Cichorieae has had its center of distribution in Antarctica. That this continent served as a path of migration for a few representatives of both tribes is nevertheless evident from the presence in Australia of a single very distinct species of the South American genus *Trichocline,* as mentioned above, as well as one of *Microseris.* This latter genus is found almost exclusively in western America, where all its relatives occur also, but there is one species, *M. pygmaea,* Don, in Chile, and another, *M. Forsteri,* is found in Australia and New Zealand (fig. 6). Two typically western Eurasian genera of Compositae, *Centaurea* (Bentham, 1873, p. 467), and *Taraxacum* (Handel-Mazzetti, 1907, p. 149) also appear to have crossed from South America to Australasia by the Antarctic route.

The patterns of distribution illustrated by these two tribes of Compositae show connections between three areas of Eurasia rich in relict species and genera: the Mediterranean region, the Sino-Himalayan region, and northeastern Asia; and three similar areas of America: the central Andes, the highlands of Brazil, and Mexico. The most striking disruption is in those groups which occur in eastern Asia and South America but are unknown in North America. The same situation undoubtedly exists in several other groups, and two cases have come to my attention. One is the very distinctive family Lardizabalaceae of the primitive order Ranales (cf. Hutchinson, 1926, p. 99), and the other is in the Bignoniaceae. This latter family is predominantly tropical and contains mostly woody vines or trees with opposite leaves. In the Sino-Himalayan flora, however, its most conspicuous representative is *Incarvillea,* a genus of perennial herbs with alternate leaves, exclusively alpine or subalpine, and found even on the lofty, arid plateaux of Tibet. Only two other genera of Bignoniaceae share with *Incarvillea* the herbaceous habit and alternate leaves: *Amphicome,* also of the Sino-Himalayan region, and *Argylia* of Chile.

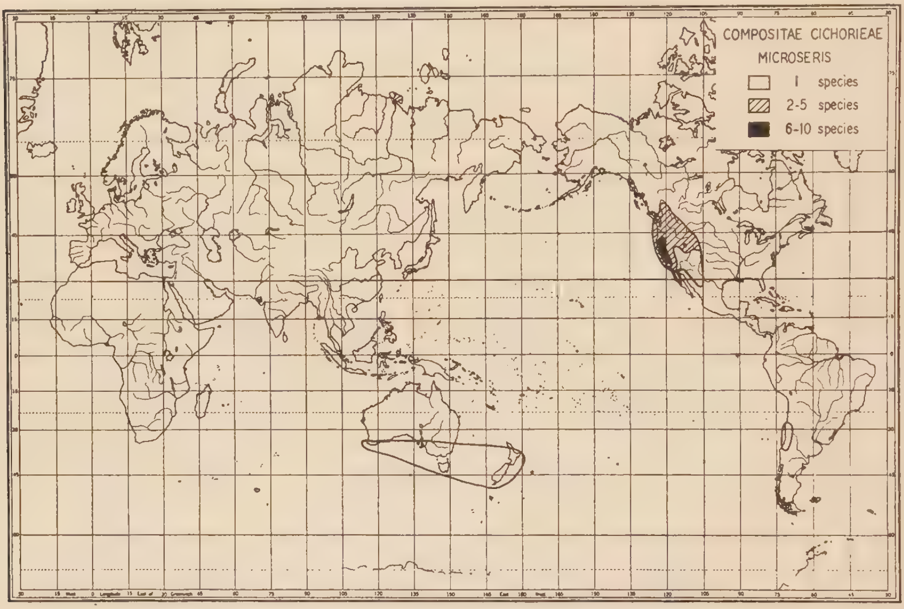

Fig. 6. Distribution of the genus *Microseris.*

I shall now descend to the bottom of the family tree of Angiosperms and show the distribution of the two most primitive subgenera of *Paeonia* (fig. 7). Moutan, which contains the two shrubby species, is the most primitive of the three subgenera of *Paeonia,* and has characteristics in common with both of the other two, while Onaepia and Paeon have relatively little in common (Stebbins, 1938). Furthermore, *P. Delavayi* of Yunnan shows a clear morphological resemblance to *P. californica* of southern California, while *P. suffruticosa* and *P. Brownii,* which are the nearest to each other geographically and in their climatic preferences, are both highly specialized in very different directions. *Paeonia,* therefore, shows a clear connection between Yunnan and southern California. A similar connection is shown by two entirely different families. *Heterocodon,* of the Campanulaceae, has for a long time been considered to be a monotypic genus of western North America, most abundant in the Sierra Nevada. Recently, however, Handel-Mazzetti and Nannfeldt (1937), the latter author the world authority on the Campanulaceae, have detected another species in Yunnan (fig. 8). *Meconopsis,* as delimited by Fedde (1936), contains forty species in the Sino-Himalayan region, all of them alpine

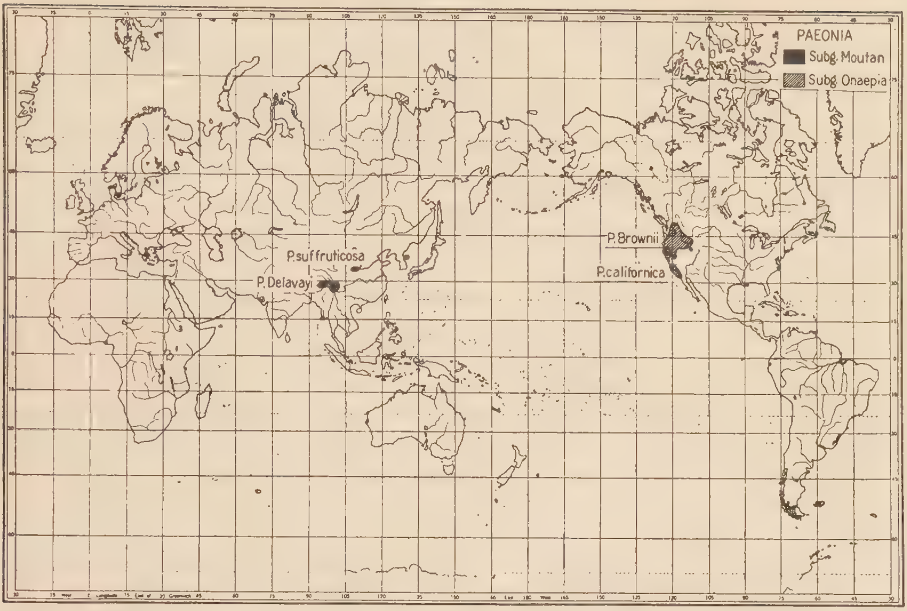
PAEONIA
■ Subg. Moutan
▨ Subg. Onaepia
P. suffruticosa
P. Delavayi
P. Brownii
P. californica

Fig. 7. Distribution of the subgenera Moutan and Onaepia of the genus *Paeonia.*

or subalpine, one in western Europe, and one, *M. heterophylla,* in California (fig. 9). Taylor (1934) has erected a new genus *Stylomecon,* for *M. heterophylla,* but admits that it differs from *Meconopsis* chiefly in habit. He also pointed out (1934, pp. 6–7) the close relationship between *Meconopsis* and *Argemone,* an American genus whose center of distribution is Mexico. There is also in the

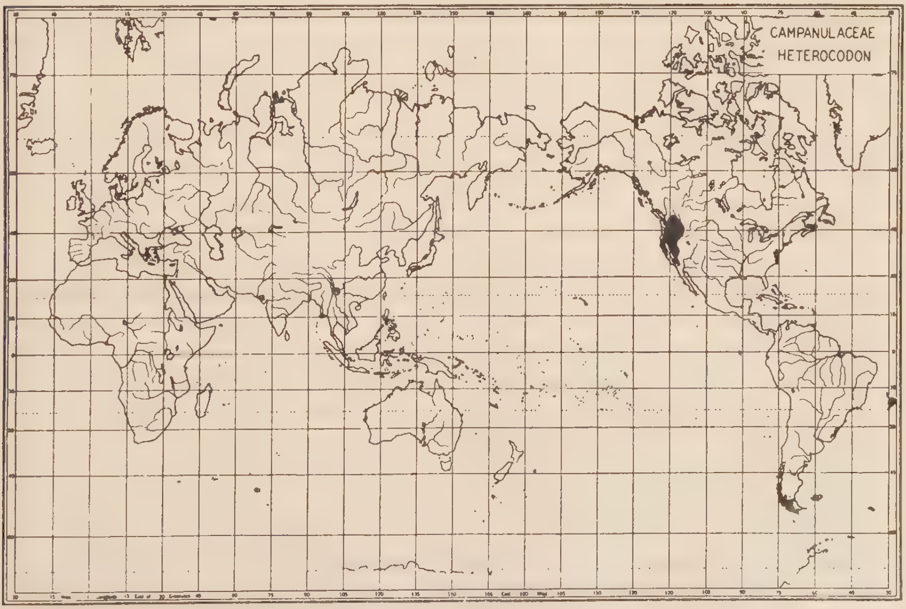
CAMPANULACEAE
HETEROCODON

Fig. 8. Distribution of the genus *Heterocodon.*

deserts of southeastern California, southern Nevada, and Utah the genus *Arctomecon,* consisting of three species of scapose, densely long-hirsute perennials which in their habit resemble some of the Sino-Himalayan species of *Meconopsis. Arctomecon* has been placed by Fedde (1936) in a different tribe from *Meconopsis* on account of a supposed difference in the structure of the ovary. In *Meconopsis* the placentae are opposite the stigmas, while in *Arctomecon* they are said to be alternate with them. In spite of careful examination of several specimens representing all three species of *Arctomecon,* I have been unable to verify this supposed difference, and in fact preparations made to show the anatomical structure of the ovary have demonstrated that in both genera each vascular bundle which forms a placenta continues into the stigma that lies directly above this placenta. Furthermore, the shape of the ovary and stigma in *Arctomecon Merriami* is very similar to that in some Asiatic species of *Meconopsis* with distinct styles, and the sepals of *Arctomecon* resemble those of *Meconopsis* rather than *Argemone* (cf. Taylor, 1934). Whether or not *Arctomecon, Stylomecon,* and *Meconopsis* represent distinct genera is not important to this discussion; they are certainly close relatives and most probably are derived from a common ancestor. They show still another connection between Sino-Himalaya and southwestern North America. I have no doubt that future monographic studies will unearth more such connections, although in their dominant species the floras of these two regions differ greatly.

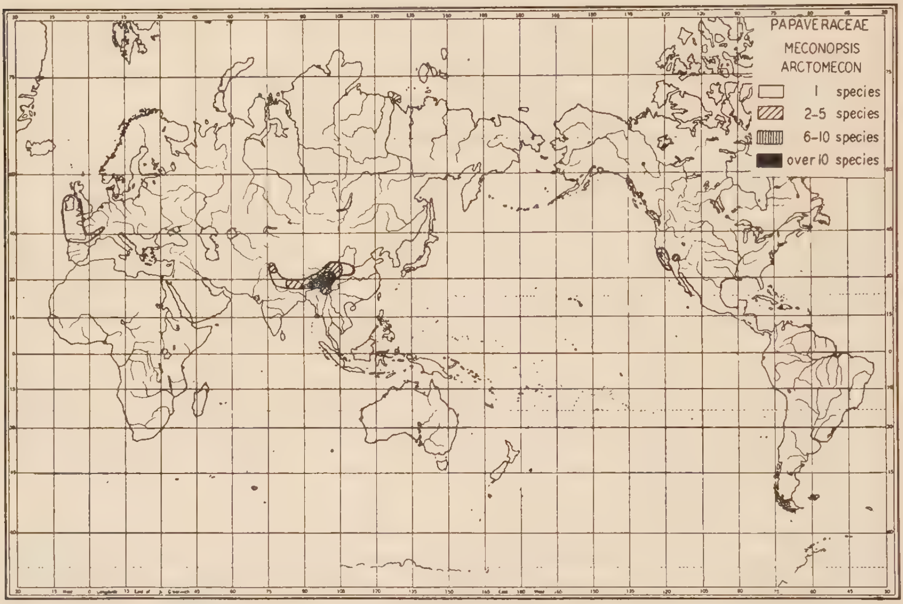

Fig. 9. Distribution of the genera *Meconopsis* and *Arctomecon.*

Still another connection between floras of the Old World and of western America must be mentioned. The occurrence of several genera only in the Mediterranean region, southern California, and the Mexican plateau has been recognized by several botanists (Turrill, 1939; Eastwood, *in litt.*). The most notable of these are *Arbutus* and *Lavatera.* In the Compositae this connection is remarkably infrequent, considering the strong representation of the family in both regions, but is well exemplified by the subtribe Filaginae of the Inuleae, particularly the genera *Micropus* and *Evax.*

To summarize: I have shown faint but definite connections between the floras of the mountains of eastern Asia and both temperate and subtropical South America as well as western North America, and similar connections between western Eurasia and the Andes. Stronger connections, representing many genera of Angiosperms, have been noted between the Mediterranean region and the Pacific North America.

For the interpretation of these connections we must rely chiefly on indirect evidence. The groups of plants under discussion are practically unknown in the fossil record, and are of types which, either on account of their herbaceous character or the type of habitat in which they occur, would not be expected to be found there. Furthermore, the leaves of the arborescent species of Compositae are of a very generalized type, such as is usually referred by paleobotanists to *Laurophyllum, Celastrophyllum,* etc., and so would be very difficult to recognize even if they do occur. The only possible fossil Composite known to the writer is the series of structures described as *Palaeanthus problematicus* Newberry, from the Upper Cretaceous clays of New Jersey. Of this form Newberry writes (1895, pp. 125–126): "Their general aspect is altogether that of a helianthoid flower; so much so that when drawings of them were sent to Dr. Gray, the leading authority on the Compositae, he did not hesitate to say that they were composite flowers. Indeed, it would be impossible to reproduce in a fossil state, at least embedded in clay, anything more perfectly representative, in general and detail, of a composite flower with twenty or more ray florets. It is evident, however, that the material composing these florets of the ray was more substantial and persistent than that of most helianthoid flowers . . ." The writer has compared the drawings with involucres of the helianthoid genus *Wyethia,* and the resemblance between the two is certainly striking; particularly so if the structures interpreted by Newberry as ray florets are regarded as the persistent receptacular bracts or paleae of an involucre from which the flowers have withered and the achenes have fallen. In modern species of *Wyethia* and other genera of the tribe Helianthieae these denuded involucres persist on the plant from one flowering season to the next, and are of such a tough, resistant character as to be admirably adapted for preservation. If Helianthieae existed during the Cretaceous epoch, Mutisieae probably did also, since their present distribution indicates an age as great or greater than that of any other tribe of Compositae, and the morphology and anatomy of the tribe is not against such an assumption. The Cichorieae, *Paeonia, Heterocodon,* and the Papaveraceae would not be expected in the fossil record, for the reasons mentioned above.

The fossil record can, however, provide indirect evidence for the age of these groups through the presence of forms whose modern representatives have ranges similar to those given above. In particular, the family Lardizabalaceae should be sought for, since the leaflets of members of this family have a very coriaceous texture, and remarkably distinctive patterns of venation. There is, moreover, a striking resemblance between leaves of *Akebia, Holboellia, Boquila,* and other genera of this family and several fossil imprints referred to *Ficus* and other genera of both Cretaceous and Tertiary age. In particular the form illustrated by Berry (1919, Pl. XII, fig. 2) as *Ficus Woolsoni* Hollick from the Upper Cretaceous of Alabama suggests the modern *Akebia lobata* Decne. of China (cf. Univ. Calif. Herb. No. 232742) and an unidentified *Holboellia* from Yunnan (Univ. Calif. Herb. No. 386410). Furthermore, the writer has compared both the illustration and the type specimen of *Clematis reticulata* MacGinitie (1933, pl. 6, fig. 4) from the Miocene of Oregon with the modern *Boquila trifoliata* of Chile (Univ. Calif. Herb. No. 278762), and has found a striking resemblance between them. If the Lardizabalaceae can be demonstrated to have been widespread in the northern hemisphere in the Cretaceous, the case for a similar age of the other groups in question is considerably strengthened.

Another line of evidence for the age of these groups is obtained from a comparison of their present climatic and ecological preference with our knowledge of past climates as interpreted from fossil evidence. All the modern groups in question, except for the Lardizabalaceae, are found predominantly in mountainous and more or less arid regions. They are not associated with forests either of the broad-leaved deciduous or the tropical evergreen type, and therefore could not have been widespread when these forests stretched throughout the North Temperate zone, as was apparently true during the early and middle Tertiary epoch in both the Old World (Kryshtofovich, 1930) and the New (Chaney, 1936). Their holarctic distribution must, therefore, have taken place either in late Tertiary time or before the beginning of this period. Their late Tertiary distribution is unlikely for two reasons. In the first place, as compared with the genera known to have acquired a holarctic distribution during the early Tertiary or earlier, such as *Acer, Alnus, Betula,* etc. (Berry, 1923), the groups in question show much less affinity between their Old and New World representatives, and form a much less conspicuous part of the floras in which they occur. They have undergone much more independent evolution in the two hemispheres than have the typical Tertiary genera, and a larger proportion of them are definitely on the wane. Their position is much more comparable to that of the coastal plain relicts of eastern North America (Fernald, 1931), for which a Mesozoic age seems most likely.

Second, in the groups which I have studied intensively, the relict genera discussed here all have more highly evolved, presumably more modern relatives which, judging from their distribution, are at least as old as the Tertiary. I have elsewhere (Babcock and Stebbins, 1938) given evidence that the genus *Crepis* was already well developed by the middle of this period; this genus is certainly more highly evolved and more modern than *Hypochaeris,* and may have been at least partly derived from it. *Hieracium,* which has developed large and distinct subgenera in both hemispheres, must also be at least of Tertiary age; it, too, is more highly evolved and probably more modern than *Hypochaeris,* while an equally good case can be made for the Tertiary distribution of ten or a dozen other relatively specialized genera of Cichorieae. The Mutisieae were probably distributed earlier than *Hypochaeris,* as is evidenced by the lesser degree of affinity between the Old and the New World species of this tribe, and by the greater proportion of relict types found in it.

In *Paeonia,* the most advanced species of the relatively modern subgenus Paeon have disrupted ranges which suggest that they have existed since middle or early Tertiary time (Stebbins, 1939). The subgenera Moutan and Onaepia must be even older. Furthermore, *Paeonia* is a genus without any close relationships, and all of the families with which it has been associated (Ranunculaceae, Berberidaceae, Lardizabalaceae) have high proportions of relict genera. *Heterocodon* is, to be sure, a rather specialized relative of *Campanula,* but this latter genus is almost certainly of Tertiary age, and may be even older. *Meconopsis* belongs to a family of which the majority of the genera have relict distributions indicating great age. All these groups, therefore, with the possible exception of *Heterocodon,* most likely attained their present distributions before the middle of the Tertiary, and judging from the climatic evidence, not later than the very beginning of this period.

Since geologists agree that the Cretaceous period was closed by mountain building, this period could have been a favorable time for the dispersal of the groups in question, and many of them were probably distributed along these post-Cretaceous mountain ranges, or the deserts which must have existed in the rain shadows formed by them. Some of the more primitive types, such as *Paeonia* and the earliest of the Mutisieae, may have reached their present limits of dispersal even earlier, and all of them must have been evolving somewhere for a long time during the Cretaceous period, since they had apparently at its close reached nearly or quite to their present stage of evolution. Fernald (1931) has ably summarized the evidence of a Mesozoic age for several elements of the flora of the eastern United States; the present study suggests a similar age for some elements of the flora of western North and South America. It strengthens the belief that all or nearly all the major families of Angiosperms, both woody and herbaceous, were already well developed by the dawn of the Tertiary period, and that many modern genera of even the most advanced families existed then. From the phylogenetic point of view, therefore, we must conclude that the differentiation of this great order of plants occurred principally during the Mesozoic era.

Based on this evidence, the following suggestion may be made in regard to past climates. At the close of the Cretaceous period, Eurasia and North America were probably connected by a system of mountains having a semiarid or arid, warm-temperate climate, and at least part of their slopes were clothed with an evergreen, shrubby chaparral type of vegetation such as exists at present on the mountains of California, and on the lower slopes of the central Andes. Such mountains very likely existed in Eurasia for a considerable part of the Cretaceous period.

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WHERE ON THE PACIFIC OCEAN ARE UPPER AIR OBSERVATIONS POSSIBLE AND MOST NEEDED?

By Louis Harmantas

This paper concerns itself, primarily, with the southwest portion of the North Pacific Ocean, approximately within Lat. 30° N to 10° S and Long. 90° E to 180°E.

In selecting the location for these upper air stations, due consideration has been given to such essentials as available transportation and degree of civilization. As a result, many of the designated stations are in the vicinity rather than in the exact position desired. With but few exceptions, the stations chosen are listed in *Radio Aids to Navigation* as weather-reporting stations. The others were selected only because of their strategic location. The accompanying tables give the locations. At a glance, the list of stations appears long, but, considering the area covered and the distance between them, the number is by no means large.

Unfortunately, there is no site for a balloon station either between the Philippines and Guam or in the southwestern part of the China Sea, two areas from which upper airs would aid materially in an exact study of typhoon formation and movement.

Southward displacement of cold fronts of the Asiatic continent are usually slow and suffer a large modification. At times they become quasi-stationary or may even retrograde. The meager and well-scattered surface reports received from this area are insufficient to locate these fronts with any degree of accuracy or to forecast either retrogression or wave developments. Upper-air

TABLE 1

Stations from Which Upper-air Observations are Possible

Stations	Internat. number	Nation	Lat.	Long.	Present surface observations	
					Made	Received
Terempa	900	Netherlands	03° 12′ N	106° 15′ E	Yes	Yes
Paracels	219 and 816	France	16 50 N	112 21 E	Yes	Yes
Pratas	814	Japan	20 40 N	116 47 E	Yes	Yes
Ishigaki Shima	645	Japan	24 20 N	124 10 E	Yes	Yes
Rosa Jima	648	Japan	24 18 N	131 20 E	Yes	Yes
Chichi Shima	660	Japan	27 05 N	142 11 E	Yes	Yes
Palau	891	Japan	07 30 N	134 38 E	Yes	Yes
Yap	893	Japan	09 29 N	138 08 E	Yes	Yes
Truk	971	Japan	07 15 N	151 50 E	Yes	No
Panape	972	Japan	06 50 N	158 12 E	Yes	No
Jaluit	973	Japan	06 00 N	169 35 E	Yes	No
Cocos Is.	000	Gt. Britain	12 05 S	96 53 E	Yes	No
Sorong	943	Netherlands	00 49 S	131 17 E	Yes	No
Dobo	970	Netherlands	05 50 S	134 20 E	Yes	Yes
Wewah	182	Gt. Britain	03 36 S	143 40 E	Yes	No
Thursday Is.	201	Gt. Britain	10 34 S	142 12 E	Yes	No
Samarai	198	Gt. Britain	10 37 S	150 40 E	Yes	No
Rabaul	422	Gt. Britain	04 20 S	152 20 E	Yes	No
Ocean	431	Gt. Britain	00 45 S	169 50 E	Yes	Yes
Vanikoro	426	Gt. Britain	11 50 S	166 50 E	Yes	No
Tulagi	425	Gt. Britain	09 05 S	160 10 E	Yes	No
Vaitupu	434	Gt. Britain	07 35 S	178 45 E	Yes	No

TABLE 2

Stations from Which Upper-air Observations are Desirable

Station	Internat. number	Nation	Lat.	Long.	Transportation	Possible
Pagan	...	Japan	18° 07′ N	145° 46′ E	Yes	Yes
Parace Vele	...	Japan	20 25 N	136 05 E	Boat entrance	?
Marcus	...	Japan	24 14 N	154 00 E	Yes	Yes
Eniwetok	...	Japan	11 30 N	162 15 E	Yes	Yes
Greenwich Is.	...	Japan	01 04 N	154 45 E	Boat entrance	Yes
Ifalik	...	Japan	07 14 N	144 27 E	Yes	Yes
Taongi or Pokaakko or Sibylla	...	Japan	14 38 N	168 59 E	No; uninhabited	?

stations between 14° and 30° N Lat. would not only solve this problem of fronts and movements, but would also provide a means of determining the high-pressure ridge west of the disturbed area, which is so essential to typhoon formation. (See "Extracts From Notes Based on Synoptic Maps and Flight in the Manila-Guam Sector," by the author.)

For a better analysis of typhoon formation we have found it necessary to extend our maps to 10° S Lat. Unfortunately, upper airs east of Long. 125° E, between Lat. 10° N and 10°S, are not available. In order to follow the movement of low-pressure fields (isallobaric lows) along the intertropic front or to determine the depth of the southwest stream in typhoon formation, we must have balloon runs from these latitudes.

We feel that the proposed distribution will give us a better understanding of the following problems:

a) General circulation.
b) Uniformity of flow in an apparently homogeneous air mass.
c) Structure of large anticyclones.
d) Rate of modification and structure of fronts moving southward.
e) Upper-air streams both during and after typhoon formation.
f) Typhoon tracks.
g) Whether convergence at low level or divergence at high levels precede in development of disturbed areas.
h) Depth of high-pressure ridge necessary west of disturbed areas for typhoon formation.
i) Trajectories of moist tongues aloft.
j) Depth of southwest monsoon required in typhoon formation.

THE PART THE UNITED STATES NAVY TAKES IN THE COLLECTION AND DISSEMINATION, THROUGH ITS CHAIN OF RADIO STATIONS, OF INFORMATION ASSISTING SYNOPTIC METEOROLOGY OF THE PACIFIC OCEAN AND THE ADJACENT AREAS

By Commander W. J. Ruble, U.S.N.

Before discussing the present activities of the Navy in connection with synoptic meteorology, I shall review briefly the early history of this subject.

During the last half of the nineteenth century the Weather Bureau had not been created and meteorology was a function of the War and Navy departments. The marine meteorological service was developed under the Navy, while the transcontinental weather service was built up and developed by the Army.

Congressional authority for the establishment and operation of a weather service over the United States was granted to the Signal Corps in 1870. As communications by land telegraph developed, the weather service under the Signal Corps gradually assumed a form fundamentally the same as at the present time. Reports from all over the country were collected by telegraph, daily weather maps printed, and forecasts disseminated.

In 1890 an act was passed by Congress transferring the responsibility for the weather service from the Army to the Department of Agriculture and this transfer was effected in 1891. The act effecting this transfer is known as the "Organic Act Creating the Weather Bureau." In effect, this act stated in part that the Chief of the Weather Bureau, under the direction of the Secretary of Agriculture, shall have charge of forecasting weather, the issuance of storm warnings, display of weather and flood signals, for the benefit of commerce and navigation and for the maintenance and operation of seacoast telegraph lines and the collecting and transmission of marine intelligence for the benefit of commerce and navigation.

While the Act of 1890 transferred the continental weather service to the Weather Bureau, the marine meteorological service was continued by the Navy Department.

For a period of approximately fifteen years both the Weather Bureau and the Navy Department were engaged not only in synoptic meteorology, but also in the construction and operation of chains of radio stations for the collection and dissemination of synoptic meteorological information.

The development of government meteorological services in the modern sense began about the middle of the last century. The marine meteorological service in the Navy Department grew out of the collection of thousands of weather observations from the logs of naval and merchant vessels. There was no specific authorization from Congress to start such a service. The potentialities of such a service were gradually brought to public attention through such work as the expeditions under Lieutenant Wilkes and Lieutenant Maury, and particularly the writings and lectures of the latter. The marine meteorological service developed by Maury in the Navy Department gradually developed into the well-known marine meteorological service which the Navy conducted up to 1904.

The entire marine meteorological service of the Navy with the exception of the publication of pilot charts was transferred to the Weather Bureau by an executive order of July 12, 1904. Essentially, this executive order took coastwise radio activities from the Weather Bureau and turned them over to the Navy Department. Marine meteorological activities on the other hand, were transferred from the Navy Department to the Weather Bureau. This executive order also provided that naval vessels and naval radio stations should assist in the collection and dissemination of meteorological information without cost to the Weather Bureau.

Therefore, since 1904 the Weather Bureau has had complete charge of all federal meteorological activities for the general public. The Navy Department has had the responsibility of making its radio stations available for the collection and dissemination and transmission of meteorological information. Both the War and Navy departments have maintained limited aerological organizations for strictly naval and military purposes.

The purpose of the naval aerological organization is to provide the specialized weather information peculiar to naval requirements. This includes aerological observations at the scene of operations of naval units at sea and ashore, to obtain data of winds aloft, temperatures, humidities, and pressures in the upper air, cloud ceilings, and similar information required for navigation of naval aircraft for scouting, bombing, smoke screens, long-range gunfire, and other activities of aircraft and surface vessels.

The part the United States Navy takes and continues to take in synoptic meteorology may roughly be classed under four headings:

1. As a contributor or observation agency, naval aerological units on board ships and at naval shore stations take meteorological observations which are used not only by the Navy, but by the Weather Bureau as well.

2. As a collection agency, our radio stations in suitably located places copy meteorological broadcasts by radio stations in foreign countries for transmission to the Weather Bureau. In many cases radio personnel at isolated radio stations are provided with limited equipment and forward the observations periodically to the Weather Bureau.

3. As a communication carrier agency the Navy communication organization transmits meteorological observations from virtually all parts of the world to the Weather Bureau. It also transmits meteorological observations collected and compiled in the Weather Bureau over its chain of radio stations and broadcasts this information in places and on frequencies which cover the entire world.

4. As a customer the Navy is, with the possible exception of civil aviation, the Weather Bureau's best and most appreciative customer.

The naval communication system is a very extensive organization and extends from ships and shore stations in the Far East, across the Pacific Ocean to shore stations on the East Coast, the West Indies, the Panama Canal, and ships operating in European waters. As a result of the advance in radio science during recent years it may be stated that the naval radio system covers the entire world and that no United States ship, regardless of the area in which she is cruising, is out of direct communication with one or more Navy radio stations.

On first consideration it might appear that such a communication organization would be very complicated. While this organization involves large investments, great numbers of men, and a large amount of intricate equipment, its basic organization and method of operation are comparatively simple.

This organization includes approximately 4000 radio transmitters, 8000 radio receivers, 2000 radio direction finders, 1500 airplanes, 500 ships, and 100 shore stations. Almost 10 per cent of the enlisted personnel of the Navy is exclusively employed in the communication organization and approximately 800 officers are exclusively or part time employed in the handling or administering of communications ashore or afloat.

Our chain of shore radio stations which possibly constitutes our major contribution to synoptic meteorology is organized on a district basis, with a district center radio station in each Naval District headquarters. These district-center radio stations are connected by primary or secondary radio circuits which serve a function similar to the telephone trunk lines connecting cities in the United States.

The primary radio circuit of the organization extends a distance of 10,000 miles in an east–west direction with major radio stations at Washington, San Francisco, Honolulu, and Cavite. It is a duplex circuit, so traffic is transmitted simultaneously in both directions. The circuit is operated automatically at speeds as high as 200 words per minute. The transmission time between Washington and Cavite or vice versa is normally about ten minutes.

At Cavite secondary circuits extend in various directions for communications with Guam, our marine forces in Shanghai, Peiping, and Tientsin, the commander-in-chief, Asiatic Fleet, and various subdivisions and units of the fleet located in Far Eastern waters. These secondary circuits are usually manually operated and traffic can move in only one direction at a time; or, in other words, only one frequency is used for both transmission and reception purposes.

The naval radio station at Honolulu serves a dual purpose. It acts as a repeater or booster station between Cavite and San Francisco. It also acts as a distribution and collection agency for communications with other naval radio stations in the mid-Pacific as well as with naval ships based on or cruising in the vicinity of Hawaii.

The naval radio station at San Francisco also serves a dual or perhaps a triple purpose, but by virtue of its location the volume of radio traffic handled is greater than that of any other station with the possible exception of our station at Washington. It acts as a repeater or booster station for traffic between Honolulu and Washington and as a distribution and collection agency for radio stations in the Twelfth Naval District and with naval vessels in the eastern Pacific.

Radio San Francisco differs from Cavite and Honolulu in that secondary circuits extend north to the radio station at Bremerton, Washington, and south to the radio station at San Diego, California.

Radio San Diego and radio Bremerton act as distribution and collection centers for radio stations and ships in the Eleventh and Thirteenth naval districts. These two radio stations connect to the primary circuit only at San Francisco.

The Atlantic portion of the naval communication system is centered at Washington, D.C., and functions in a manner similar to that of the Pacific organization.

As a contributor to the Weather Bureau's meteorological service the Navy utilizes meteorological stations equipped with complete aerological equipment and personnel trained in meteorology located at the thirteen naval air bases named below:

Lakehurst, N. J.
Anacostia, D. C.
Norfolk, Va.
Pensacola, Fla.
Annapolis, Md.
San Diego, Calif.
Pearl Harbor, T. H.
The Canal Zone
Seattle, Wash.
Sitka, Alaska
Quantico, Va.
Dahlgren, Md.
Virgin Islands

Additional meteorological stations are maintained at the naval stations at

Dutch Harbor, Alaska
Guam
Samoa

Limited aerological equipment is operated by radio operators at radio stations:

San Nicolas Island, Calif.
San Clemente Island, Calif.
Guantanamo, Cuba
Cape Hatteras, Va.
Cape Lookout
Cape Arguello, Calif.

Meteorological observations taken at most of the stations listed above are forwarded to the Weather Bureau and in some cases they are also forwarded to adjacent Navy meteorological centers.

The following ships of the Navy are supplied with aerological equipment and personnel especially trained in meteorology:

U.S.S. Pennsylvania, flagship of the U.S. Fleet
U.S.S. California, flagship of the Battle Force
U.S.S. Indianapolis, flagship of the Scouting Force
U.S.S. Augusta, flagship of the Asiatic Fleet
U.S.S. Saratoga
U.S.S. Lexington
U.S.S. Ranger
U.S.S. Yorktown
U.S.S. Enterprise
U.S.S. Wasp
U.S.S. Wright
U.S.S. Langley

The following ships are also equipped with pilot balloon equipment and one trained man to take upper-air soundings over the ocean:

U.S.S. Henderson
U.S.S. Chicago
U.S.S. Ranger
U.S.S. Black Hawk
U.S.S. Gold Star

The following naval stations make aircraft flights for the collection of upper-air temperatures and humidity. These observations are used both by the Navy and by the Weather Bureau:

Lakehurst, N. J.
Norfolk, Va.
Pensacola, Fla.
San Diego, Calif.
Seattle, Wash.
Pearl Harbor, T. H.
Coco Solo, C. Z.
Virgin Islands

The Naval Air Station, Anacostia, D. C., the U.S.S. Lexington, and the U.S.S. California are equipped with apparatus and personnel for making radio meteorgraph observations utilizing balloon radio devices developed by the Navy Department. Additional radio meteorological equipment is now being supplied to the Naval Air Station, Lakehurst, Seattle, San Diego, Pensacola, the U.S.S. Indianapolis, and the U.S.S. Yorktown.

The situation at the Navy Yard, Cavite, in the Philippine Islands, is rather unique and was not mentioned in the foregoing paragraphs. A very complete meteorological station with equipment and trained personnel is maintained there to collect and disseminate by radio a weather broadcast covering the Far East. This activity was established by the Navy in accordance with international agreement and is the only activity of the kind conducted by the United States.

As many of you know, there are, in various parts of the world, approximately 3200 meteorological observation stations exclusive of ship stations and approximately 530 radio stations which broadcast meteorological observations. Our radio stations at Cavite, Honolulu, Dutch Harbor, and San Diego copy meteorological broadcasts located in the Far East, South Seas, Russia, and Mexico for transmission to the Weather Bureau.

A considerable number of naval radio stations such as Eureka, California, Point St. George, California, Astoria, Oregon, and Tatoosh, Washington, etc., act as miniature weather bureaus for shipping in their immediate area. These stations are equipped with limited equipment such as wind gauges, barometers, and wet- and dry-bulb thermometers. Observations are taken by the radio personnel and broadcast for local use and for transmission to the Weather Bureau.

Our meteorological broadcasts of international interest in the Pacific are transmitted by the high-power naval radio stations at Cavite, Honolulu, San Francisco, Balboa, Canal Zone, and Washington. These broadcasts are usually made twice daily on as many as five different frequencies suitable for covering the entire world.

The geographical layout of the primary and secondary circuits of the naval communication system resembles a giant letter "T" with two crosses rather than one. If we could look down upon the earth from a position many miles above Hawaii, we would see the primary circuit represented by an imaginary line 10,000 miles long extending east and west from Washington via San Francisco and Honolulu to Cavite. At the eastern end of this line we would see one secondary circuit represented by an imaginary north–south line extending from Boston to Panama. At San Francisco we would see an imaginary north–south line or second cross of our letter "T" which represents the secondary circuit connecting Bremerton and San Diego to the primary circuit.

At the ends of these imaginary lines and at various places along these lines we would see other imaginary lines radiating like the spokes of a wheel from district-center stations to ships, airplanes, and small shore radio stations within the district's service area.

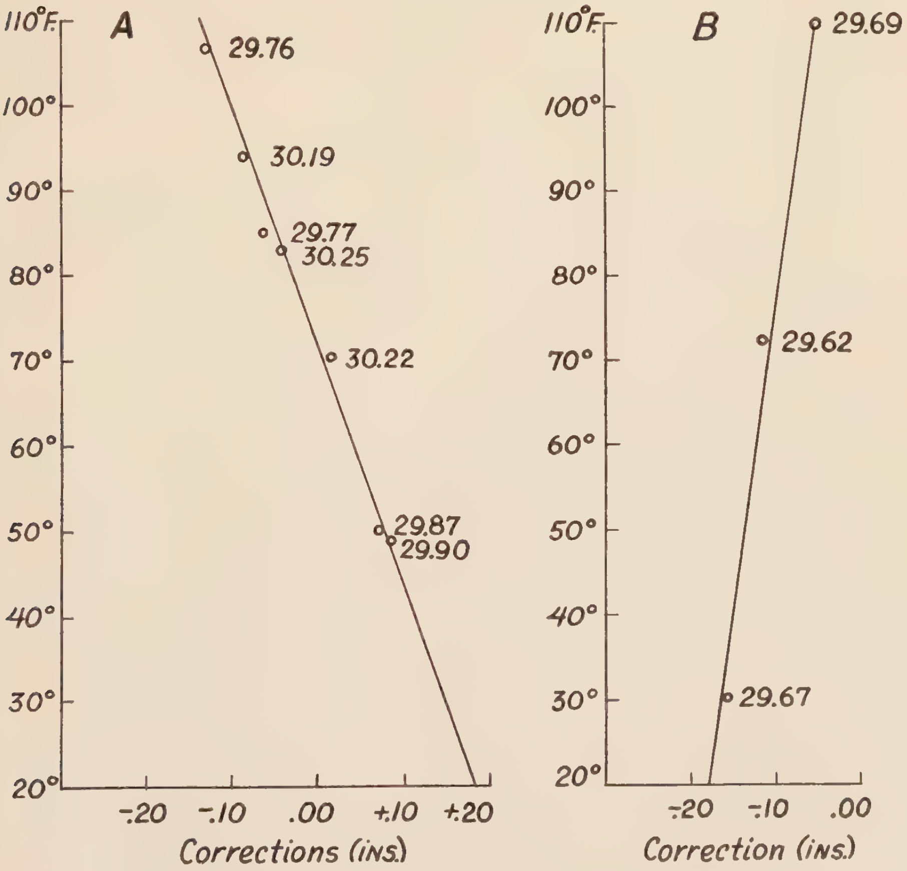
An examination of the chart will show that broadcasts of meterological information by our five major radio stations consume an appreciable part of each twenty-four hours. While this meteorological information is flowing out from the Weather Bureau offices in Washington and elsewhere, a vastly greater number of words is moving in to these offices from all parts of the world over the Navy's chain of radio stations.

DETERMINING THE VARIABLE CORRECTIONS TO BE APPLIED TO ANEROID BAROMETERS NOT WHOLLY COMPENSATED FOR TEMPERATURE

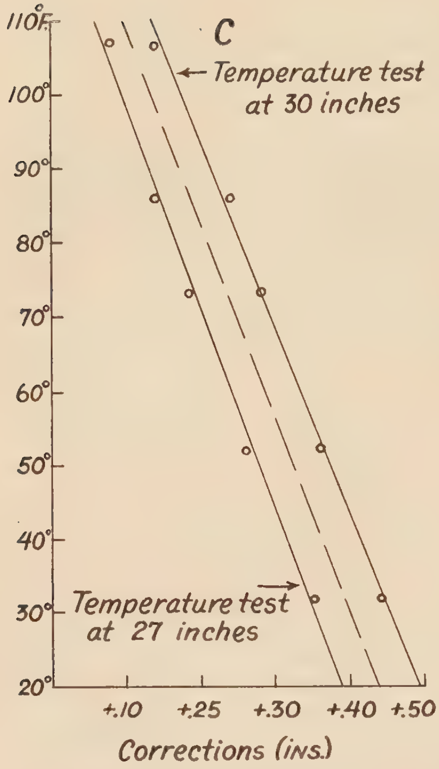
By Roger C. Nichols

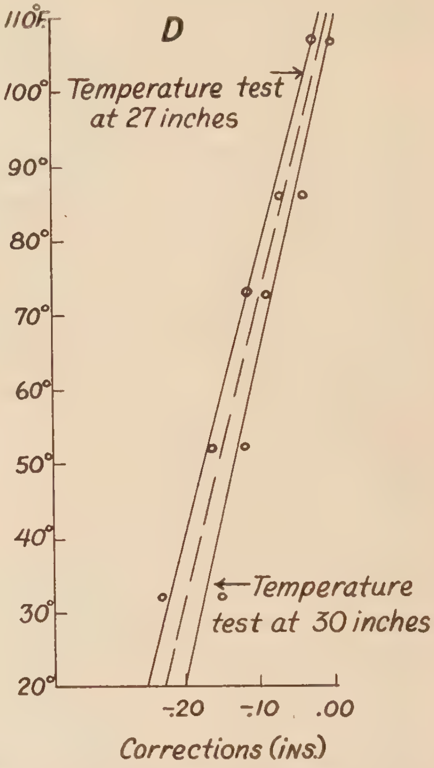
Owing to the scarcity of vessels in the Pacific Ocean, it has been necessary to obtain radiographic weather reports for forecasting purposes from many ships having aneroid barometers that are poorly compensated for temperature. Whenever temperature tests reveal an instrument to be uncompensated, the ship's master is advised of the results of the test and it is recommended to him that it be replaced.

It has been found, however, that some masters are unwilling to go to the expense of purchasing a dependable replacement instrument. For cases involving the continued use of uncompensated aneroids, the Weather Bureau is now resorting to the practice of providing corrections designed to take care of errors arising from the temperature factor.



Tests showed that many aneroid barometers aboard ship varied 0.20 to 0.30 inch for a temperature range from 50° to 100° F., and in one extreme case the corrections varied 1.64 inches for a temperature range from 30° to 94° F. For such instruments, graphs were constructed for use in determining the





corrections to be applied at various temperatures of the instrument. Temperature tests at atmospheric pressure indicated that corrections for temperatures from about 40° to 100° F., when plotted on a graph, would lie along a straight line. Additional tests made with the equipment in the Instrument Division of the Weather Bureau showed the graph of the corrections generally to have a very slight curvature for this temperature range, but of such small magnitude that the corrections for practical purposes could be considered as lying on a straight line. There seems to be one exception, and that is for those barometers in which a degree of compensation has been secured by deliberately leaving a small residuum of air in the vacuum cell. In this case the corrections for instruments tested to date take the shape of a definite curve.

Graphs A and B are examples of graphing corrections. Temperatures in degrees Fahrenheit are plotted as ordinates and barometric corrections are plotted as abscissas. A is for an aneroid which is uncompensated for changes in temperature of the instrument at 30 inches; B is for an aneroid which is overcompensated by the use of a bimetallic bar. In both cases the straight line corrections agree closely with the correction points. It should be noted that with uncompensation the barometer reads high with high temperatures, and low at low temperatures, and for overcompensation the reverse occurs. Why an uncompensated instrument reads higher with an increase in temperature is mostly because of the decrease in the stiffness of the large D spring at higher temperatures. As the spring weakens, the air pressure forces the cell walls closer together. This action is transmitted through the multiplying mechanism and makes the pointer indicate a higher pressure. Overcompensation can be caused when the bimetallic bar is too large or when it leaves an excessive amount of air in the vacuum cell. Sasaki[1] has also shown that some instruments which are compensated for a 30-inch pressure are overcompensated at lower pressures. A ship's aneroid having complete compensation for temperature at 30 inches would show the corrections to be in a vertical position on the graph. The temperature tests of aneroids A and B were made at atmospheric pressure. During the test of B the pressure remained practically constant, but during the test of A, although the pressure varied from 29.76 to 30.25, or 0.49 inch, the corrections fell along a straight line.

Another factor to be considered in furnishing variable corrections for temperature is the change in corrections, and hence of the slope of the temperature correction lines with a wide range in pressure. Temperature tests for C and D were made at constant pressures of 27 and 30 inches. This range was more convenient for testing purposes than the 3-inch range which could be expected aboard ship from 27.80 to 30.80, and it would still show the reactions of an instrument to temperature and pressure fluctuations. The slopes of the variable corrections in aneroid C at 27 and 30 inches are nearly the same. The correction lines at 27 and 30 inches for aneroid D also are almost parallel. For both instruments, however, there is a slight convergence as the temperature increases. The difference in correction for aneroid C at 100° between 27 and 30 inches is 0.08 inch and at 30° the difference is 0.11 inch. A temperature test of this instrument made at a constant pressure of 28.50 showed the correction line to fall midway between the 27- and 30-inch temperature correction lines. Therefore, if corrections were issued for this instrument from a temperature test made at a constant pressure of 28.50 inches, as indicated by the dashed line, the corrections would only be in error 0.04 inch for the extremes of 27 and 30 inches at 100°, and 0.06 inch at 30°. For aneroid D, the error in corrections would be 0.01 inch at 100° and 0.02 inch at 30°.

It should be pointed out that at a constant temperature of about 70° any change in correction with change in pressure is due to improper pressure calibration. The degree of accuracy of a variable temperature correction for a 2- or 3-inch range in pressure, therefore, depends mostly on the pressure calibration of the barometer. If a barometer were properly calibrated for pressure, the only error in the temperature correction would be due to change in slope of the corrections for 27 and 30 inches and would increase slightly with distance above or below room temperature. An inspection of graph C shows that at 70° there is a difference in correction of 0.09 inch for the 3-inch range due to improper pressure calibration. After running this test, the instrument was recalibrated and adjusted so that there was no change in correction at 70° for the 3-inch range. Graph E shows the result of the test made after the aneroid was properly adjusted. The general slope of the correction lines remains about the same as in C, except that recalibration has caused the lines to be squeezed together so that there is a constant pressure correction at 70° for the 3-inch range. The correction lines continue to have a wide spread at the higher temperatures, but there is a marked improvement in the usual operating range aboard ship from 50° to 90°. Tests of this instrument therefore indicate that it is desirable whenever possible to make pressure calibration adjustments before issuing variable corrections.

Temperature and pressure tests have thus far shown that it is possible to temperature-test an aneroid at atmospheric pressure of about 30 inches, and from this test furnish corrections for a ship's instrument which will not be in error over 0.02 or 0.03 inch for a 2-inch range in pressure unless the instrument is faulty because of other defects such as excessive friction in the chain

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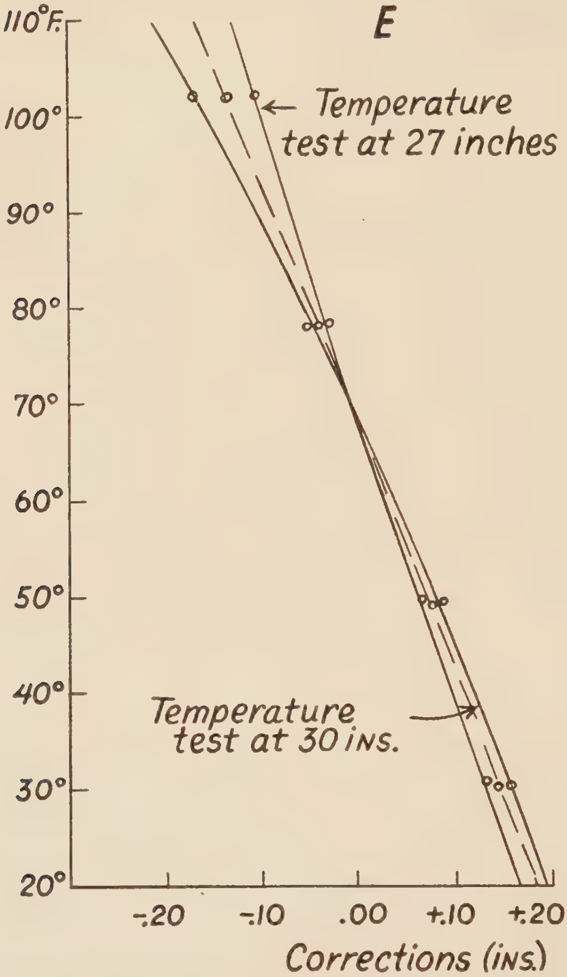
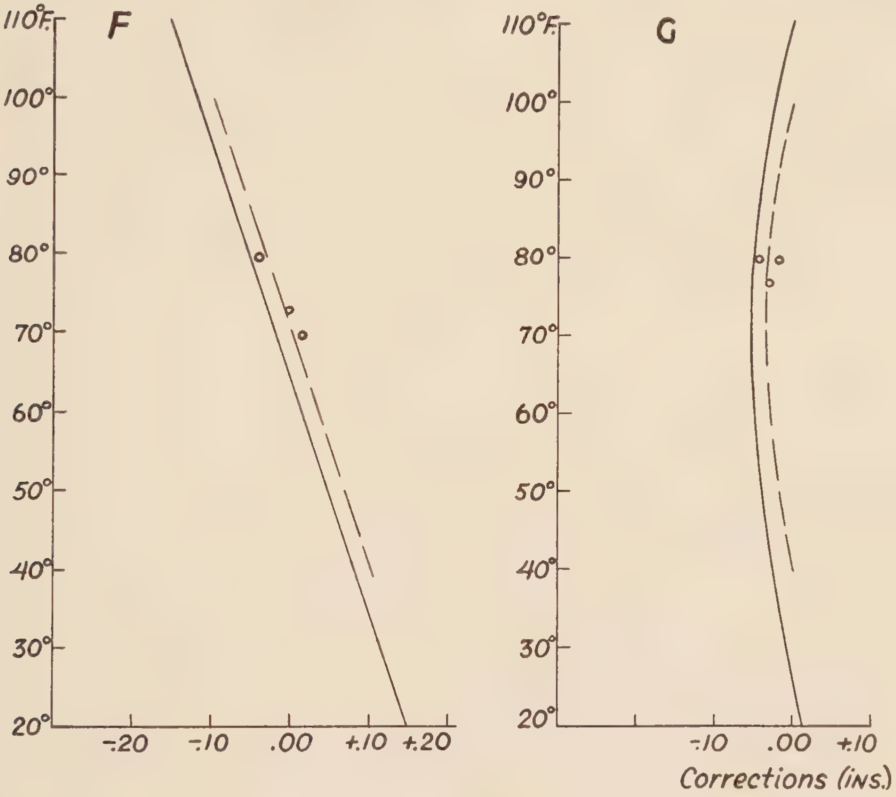
[1] T. Sasaki in Report No. 41, September, 1929, of the Aeronautical Research Institute, Tokyo Imperial University, on the Effect of Temperature Changes Upon Altitude.



and bearings. The ship's officers in applying the correction to the observed readings have only to know the temperature of the barometer. Many aneroids have attached thermometers. For other aneroids a thermometer can be mounted on the chartroom wall with the bulb of the thermometer touching the aneroid. The thermometer bulb is then encased in putty to make it react more slowly and at a rate approximately the same as that of the barometer.

The corrections and the slope of the temperature correction line at constant pressure will not vary over a period of time unless there is a change in the mechanism of the instrument, such as the slight shifting of part of the mechanism, overstraining of the D spring, or a gradual leakage of air into the vacuum cell. Advantage is now being taken of this fact in furnishing variable temperature corrections for a ship's aneroid at some future date after the instrument has once been tested. Up to the present time, it has been necessary to retemperature-test a barometer each time a new variable correction was furnished to a ship. This has been difficult to do, as many ships are not regularly in port long enough for a complete test. In making a barometer comparison for a compensated reliable aneroid, the instrument remains in its position aboard ship. The officers make three or more comparative readings when the ship arrives in port and mail them to the Weather Bureau Office on a card on which the time of each reading is shown. In computing the correction for the aneroid, the comparative readings are compared with standard sea-level pressures. This same procedure is now used for furnishing new variable temperature corrections after a poorly compensated instrument has once been temperature-tested, except that the officers also have to furnish the temperature of the aneroid for each comparative reading.

Graphs F and G are examples of how this type of correction is used. The solid line for F represents the variable temperature correction line obtained from testing the instrument. At a later date, the ship returns to port and the officers furnish three comparative readings and the temperature of the instrument for each reading. The three corrections for these readings are plotted on the examples as dots. A dashed line is drawn parallel to the slope of the solid line and through the correction points in such a manner as to give a mean difference in the change in correction from the previous test. It can be seen that the instrument has changed its correction about 0.02 inch. This small change in correction will not affect the slope of the correction line materially, and a set of variable temperature corrections based on the dashed line can be furnished. If the correction point were 0.10 or 0.15 inch from the original correction line, it would be proof that a mechanical change had taken place in the instrument and a new temperature test should be made. At the present time, a sufficient number of tests has not been made to permit stating how



much change in correction can take place without changing the slope of the correction line. An arbitrary limit of 0.04 inch in either direction from the correction line at room temperature has been agreed upon. For aneroid G the same practice can be followed as was done for F, except that in this instrument the correction line is in the shape of a curve.

Ships do not obtain all their barometer comparisons at one port. One transpacific ship may obtain a comparison at San Pedro, and the next trip the ship may go to Portland and the comparative readings be furnished there. By informing the port stations of the results of all temperature tests resulting in the issuing of a variable temperature correction, they are in a position to furnish a new set of temperature corrections from the three or more comparative readings by the ship's officers.

This plan of furnishing corrections for poorly compensated aneroids after the instrument has once been temperature-tested has only recently been put into operation and is limited to vessels operating in the Pacific. The tentative results have been favorable, and it is expected that its use will improve the accuracy of barometric observations. Mean corrections will continue to be furnished for all instruments except those which are not properly compensated for temperature. When such an instrument is found, the first effort will of course always be to have it replaced, but, this failing, corrections for temperature shall be furnished.

THE PRESENT STATUS OF INVESTIGATIONS OF TYPHOONS AND DEPRESSIONS IN JAPAN

By Sakuhei Fujiwhara

In 1933, Professor T. Okada submitted to the Fifth Pacific Science Congress a paper[1] on the status of typhoon investigations in Japan up to that time. The present paper brings the subject up to date, and also gives information on depressions, and on fronts and air masses, in Japan and its vicinity.

Statistical investigation.[2]—The monthly frequencies of the various low pressures in Japan and its vicinity since 1932 have been as shown in table 1.

From this table, which contains all the various low pressures—typhoons, cyclones, depressions, and secondary depressions—it will be seen that depressions appeared most frequently in May, followed by November, and most seldom in August, followed by February, whence it is likely that double periodicity prevailed in this area. For typhoons we have the next table.

From table 2 it will be seen that typhoons appeared most frequently in September and least so in March, so that simple periodicity prevailed, which was also the case in the previous report by Professor Okada for the period 1897–1911. The data for the period 1912–1931 are

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
Mean.......	0.1	0.1	0.2	0.05	0.5	0.45	2.35	3.4	3.3	1.8	0.5	0.05	12.8

The number of typhoons during this period totaled 256.

Including those already reported by Professor Okada, we have for the years 1898–1938 the frequency data summarized in table 3.

We have thus the annual periodic occurrence of typhoons for Japan and its vicinity. It might be added here that owing to the increased number of new meteorological stations in the southern ocean, Japan's typhoon statistics have in recent years become much more accurate than they formerly were.

The average rates of travel of depression centers during the 7 years 1932–1938 in Japan and its vicinity are shown in table 4.

From table 4 it will be seen that depressions in Japan and its vicinity move quicker (1) in winter than in summer, (2) over sea than inland, and (3) in high latitudes than in low latitudes, as they do in other countries, although the number of years covered by the statistics here is not sufficient for indicating the true characteristics of the region concerned.

The inner region of a typhoon.—In the previous report by Okada, it was stated that Y. Horiguti had investigated the structure of the outer part of typhoons of comparatively low latitudes. D. Nisimura[3] later studied the structure of the inner part of a typhoon that visited Naha on September 28, 1929. This typhoon included the phenomenon commonly called the "eye of the storm." For the pressure distribution at that time, from the typhoon center up to a radius of 250 km., he obtained the formula

$$p = 754.2 - 38.2e^{-mr^2}$$

where $m = 6.4 \times 10^{-3}$, r is the radial distance in km., p is the pressure in mm. Hg. He also found a striking asymmetry of pressure distribution, owing

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[1] *Proc. 5th Pac. Sci. Cong., Canada*, 1933, 3:1981–1983.

[2] The statistics given in this section are used with the permission of the Central Meteorological Observatory, Tokyo.

[3] *Jour. Meteorol. Soc. Japan*, 10(1932):113.

TABLE 1

Depression Frequency in the Area Long. 110°–160° E, Lat. 4°–60° N

Year	Month												Total
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
1932	39	26	36	33	39	37	29	21	28	26	28	26	368
1933	34	43	35	36	48	38	29	24	32	31	36	26	412
1934	28	24	34	31	24	23	45	24	30	35	36	20	354
1935	33	34	35	43	36	34	31	22	33	31	32	27	391
1936	25	36	26	35	43	36	37	38	39	42	44	30	431
1937	53	39	38	30	41	52	42	44	43	45	52	54	533
1938	39	35	50	55	54	39	28	35	41	52	41	41	510
Mean	35.9	33.9	36.3	37.6	40.7	37.0	34.4	39.7	35.1	37.4	38.4	32.0	428.4

TABLE 2

Typhoon Frequency in the West Pacific Area

Year	Month												Total
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
1932	1	0	0	0	0	1	3	2	3	2	2	1	15
1933	0	1	0	1	0	1	4	3	5	6	1	0	22
1934	0	0	0	2	0	0	2	4	7	4	4	1	24
1935	1	0	0	1	2	2	7	4	6	3	3	2	31
1936	0	0	0	2	0	0	5	4	4	4	5	0	24
1937	0	0	0	0	1	1	2	7	4	4	2	2	23
1938	1	0	0	1	2	2	4	4	10	4	0	1	29
Mean	0.4	0.1	0.0	1.0	0.7	1.0	3.9	4.0	5.6	3.9	2.4	1.0	24.0

TABLE 3

Typhoon Frequency, 1897–1937

Period	Month												Total
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
1897–1911	1	0	3	2	9	11	29	55	56	52	22	7	247
1912–1931	2	2	4	1	10	9	47	68	66	36	10	1	256
1932–1938	3	1	0	7	5	7	27	28	39	27	17	7	168
Total	6	3	7	10	24	27	103	151	161	115	49	15	671
Mean	0.14	0.07	0.17	0.24	0.57	0.64	2.45	3.61	3.85	2.73	1.16	0.37	16.0

TABLE 4

Velocity of Depression Centers

	Month												Year
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
Siberian Maritime Province	45.0	43.6	42.2	38.7	35.1	30.1	31.0	33.7	29.6	38.9	21.5	43.9	34.1
Northern Manchukuo	40.4	27.5	33.0	34.6	31.2	24.9	23.5	30.5	30.5	34.1	38.1	47.5	32.6
Southern Manchukuo	40.3	38.3	38.9	36.6	34.4	23.8	32.6	27.1	30.6	38.8	49.5	35.4	35.6
Yellow Sea	42.2	46.9	42.3	42.7	35.5	33.2	26.2	23.7	32.1	32.8	31.4	33.0	34.0
Hwang-Ho Region	38.5	32.9	34.1	33.9	30.0	23.1	28.5	23.4	36.7	27.0	36.3	29.7	30.4
Yangtze Region	38.8	35.5	43.9	41.8	38.4	32.2	26.4	26.2	36.0	31.2	34.5	42.2	35.0
China, Eastern Sea	40.3	34.9	48.3	33.7	33.3	27.6	22.6	19.9	26.5	27.0	32.0	38.5	31.1
Japan Sea	49.4	32.9	31.7	40.7	39.5	32.1	28.1	30.2	29.2	37.4	38.2	34.5	33.5
Japan Proper	30.3	40.5	36.8	42.6	25.3	29.3	27.3	31.3	41.6	48.6	63.9	58.6	34.2
Okhotsk Sea	30.3	36.2	39.8	35.3	39.7	31.1	35.5	33.7	35.9	35.9	38.6	36.0	35.6
Japan, Eastern Ocean	43.0	42.4	46.0	47.3	43.9	37.7	31.7	34.9	36.6	46.4	46.8	47.1	42.2
Japan, Southern Ocean	45.3	45.4	43.8	38.8	36.8	29.8	20.5	19.6	24.7	29.0	38.0	43.2	33.1
Southern Ocean	23.4	....	....	24.2	19.6	20.2	20.4	23.1	22.0	17.2	27.2	25.2	21.9
Mean	39.5	39.8	41.7	39.2	35.4	30.7	26.0	27.5	28.8	34.9	39.0	39.6	34.5

to topography, at the time that the eye of the typhoon passed Yokohama on October 8, 1928.

Y. Horiguti[4] undertook the analysis of a typhoon that passed the Inland Sea in September, 1933, and wrecked the steamer *Yashima Maru*. He obtained reliable data concerning this typhoon when it was passing the Isigaki Zima Meteorological Observatory. With respect to wind distribution, he distinguished three regions in this typhoon: the outer region, which included the area from the outer margin up to 50 km. of the central distance; the intermediate region, which lay between 30 and 50 km. of the radius; and the inner region, inside the 30-km. radius. The wind velocity increased gradually in the outer region as it approached the center, reaching the maximum at the 50-km. radius, the inner boundary of the outer region; then it began to decrease, although slowly, up to the 30-km. radius, the boundary of the inner region; whence it dropped very quickly, so that only breezes prevailed in the central region. Rainfall, which was violent in the outer and intermediate regions, was rather slight in the inner region. The height at which the gradient wind was reached was about 100 m. above the ground in the inner region, while it was about 1000 m. in the intermediate and outer regions. In the inner region, the tangential wind component and the atmospheric pressure were well expressed by

$$v = r\,\theta = ar + br^2$$

$$(p - p_0)^2 = \frac{c^2\,r^2}{d^2} + c^2$$

where r and θ are respectively radial distance and azimuthal angle, and p_0, a, b, c, d, are constants. Horiguti did not find any trace of descending air at the eye in this case.

B. Haurwitz,[5] who also made investigations along the same lines, concluded that there was a descending motion in the eye of the Manila typhoon of October 19–20, 1882, while Father Deppelmann preferred to suspend judgment in the matter[6] as already done by Professor Okada.[7]

The height of a typhoon, its upper current and upper clouds.—In the same paper as that mentioned above, Haurwitz maintained that the height of a typhoon must be fully 10 km. above sea level—a view already held by Japanese meteorologists from years back[8] notwithstanding E. Knipping's opinion of a low height for typhoons.[9] Japanese meteorologists, who had noted that cirrus clouds accompany a typhoon, did not subscribe to Knipping's opinion, particularly as K. Kondo[10] supplied an example of a typhoon that had actually passed across the central mountain range (3000 m.) of Taiwan (Formosa). Recent years have given us abundant data based on precise observations, by means of which Arakawa and Takeda[11] reached conclusions similar to those of Haurwitz. Arakawa[12] has developed the theory of a warm centered depression—a theory in connection with which both he and Takeda collected data of inflowing as well as outflowing cirri over a typhoon with cyclonic as well as anticyclonic deviations. They maintain, moreover, that the central high temperature is to be found not at the ground level, as in the classical convectional theories,[13] but at the middle and higher altitudes of the internal ascending column (not the eye), owing to the fact that the lapse rate is smaller than the surrounding air mass as a result of vigorous condensation.

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[4] *Rept. Imp. Marine Obs., Kobe*, No. 70, 1934.

[5] *Monthly Weather Rev.*, 63 (1935): 45–49.

[6] "Temperature Conditions in the Eye of Some Typhoons," Weather Bureau, Manila Central Observatory, 1937.

[7] *Mem. Imp. Marine Obs.*, 1 (1922): 27–36.

[8] Z. Onuma, *Jour. Meteorol. Soc. Japan*, 1915, pp. 460–473; Y. Yosida, *ibid.*, 1922, pp. 622–628; K. Han'i, *ibid.*, 1925, pp. 19 ff.

[9] Hann, *Lehrbuch der Meteorologie*, 3d ed., p. 618.

[10] *The Climate, Typhoon, and Earthquakes of Formosa*, 1914, Taihoku.

[11] *Jour. Meteorol. Soc. Japan*, ser. 2, 13 (1935): 546–549.

[12] *Geophys. Mag.*, 10 (1936): 43.

The Muroto typhoon.—On September 21, 1934, a typhoon, the most disastrous ever recorded in Japan, visited the central part of the country, first striking the land at Muroto, where the barometer dropped to 648.0 mm. Hg. (reduced to M.S.L.), and, passing over Osaka and Kôbe, escaped to the Pacific Ocean, leaving more than 3000 persons killed, 63 steamers wrecked in harbors, and innumerable houses, bridges, farms, forests, railway trains, roads, telegraphs, etc., destroyed, the total damage amounting to more than 800,000,000 yen (1 yen was then worth about 29 cents, or 1*s.* 2*d.*). A number of reports on this typhoon have been published by various authorities, that from the Central Meteorological Observatory being the fullest, consisting of 520 pages and 250 illustrations. A short abstract of this report follows:

Evolution of the typhoon, by S. Fujiwhara.—The typhoon originated in a valley of low pressure between two high pressures, the one the Philippine high, the source of the southwest monsoons, which is an extension of the high of the southern hemisphere across the equator, and the other the high of Ogasawara (Bonin Is.), the source of the northeast trades. First, on the 12th, the wind directions in this region were diverse, small depressions generating here and there with thunder showers. These depressions united one after the other and gradually built up a young typhoon on September 16, with a central depth of about 750 mm. Hg. Progressing northwestward at a rate of about 20 km. per hour, it reached Okinawa (Loochoos) on the morning of September 20, whence it recurved to the northeast. The symptoms attending the change in course were: (1) the southern air current on the eastern side of the typhoon became very energetic, while in front of it a marked line of discontinuity had developed; (2) a high pressure appeared in Manchukuo; (3) a so-called "gate of the typhoon" opened on the north; and (4) the westward component velocity of the typhoon center slowed down.

Landing and passing over Japan Proper of the typhoon, by Y. Horiguti.—The typhoon passed over Japan in four sections, so to speak. The first center landed by Muroto Cape and, passing over Kôbe, gradually faded away; the second center originated east of the first and developed with the decay of the first. The second passed northeastward and gradually faded away, the third took its place, and then the fourth. The first center was accompanied by a secondary that also ran northeast on the eastern side of Muroto Cape. This was proved by the barogram at Muroto, in which it is possible to see two minima, one of 689.9 mm. and the other of 684.0 mm., with a time difference of 15 minutes. The eye of the typhoon was observed at Kôbe and its eastern vicinity.

Discontinuity and air masses, by T. Otani and S. Oma.—When the typhoon approached Japan Proper, three current systems found their way into the typhoon with the result that three air masses came into contact. They were: (1) the south of southeasterly warm, moist air mass, (2) the northeasterly cold, moist air mass, and (3) the northwesterly cold, dry air mass. At places warm dry air was observed in a southerly current, which was proved to be due to föhn action. In the beginning the line of discontinuity of temperature did not coincide with the current front. The former was situated north of the latter. Later these two approached each other and finally coincided on the

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[13] Ferrel-Espy's convectional theory in any text book, e.g., Shaw's *Manual of Meteorology,* I:301.

20th. The largest temperature difference between the two sides of the main front was 7° C. Occlusion and backbending on a small scale were observed on its crossing land. The typhoon center moved almost along the main front of the southerly warm current, which lay south-southwest–north-northeast, at some distance to north-northeast from the center. The center of the warm sector always preceded the typhoon center. The typhoon moved northeastward, while the air current in the warm sector moved in directions from southeast, east, northeast, and north, according to the whirling motion of the typhoon; the direction of isobars in the warm sector being south-southeast to north-northwest, very different from a European depression, as maintained by the Norwegian school.[14]

Distributions of wind velocity and pressure, by S. Fujiwhara.—The distribution of meteorological elements in the typhoon were not symmetrical. The air pressure was lowest at the center, increasing rapidly with increased distance from the center. The wind velocity, which was greater at the center, weakened as the central distance increased. Although these distributions were too complicated to be represented by mathematical formulae, their general tendency could be said to be parabolic. On the weather chart, we could not discern any trace of discontinuity of wind direction or wind velocity, although the anemograms recorded very distinct sudden changes in wind velocity and direction due to passage of the typhoon.

Cloud distribution, by K. Sasaki.—In the southern stations, cirri clouds were seldom observed in the typhoon area. They appeared, however, in Japan Proper, preceding the typhoon. The boundary of the three air masses was exhibited earlier and more distinctly by distribution of cloud motion than by surface air currents.

Upper air current, by H. Arakawa and Y. Yamahata.—By constructing isobars at various levels it was found that the circular form of typhoon isobars was distinct at a height of 4000 m. above sea level. At levels of 3000 m. and 4000 m., sharp discontinuities were observed over the Korean peninsula, which, however, were not very marked on the surface weather chart. It was also found that the height of wind maximum was high in the rear but low in the front of the typhoon.

Distribution of amount of rainfall, by T. Satô and S. Oma.—The zone of greater precipitation appeared on both sides of the typhoon track. Along the latter the amount of rainfall was comparatively small. The number of stations at which the rainfall exceeded 400 mm. during the three days of the typhoon was 8, of which that measured at Nagasawa, Kôti Prefecture, was 506 mm. The number of stations at which the rainfall amounted to more than 300 mm. in one day was 13, of which that measured at Senzoku, Ehime Prefecture, was 376 mm. and that at Odaihara, Mie Prefecture, 373 mm. The heaviest rainfall was observed in the region of northeasterly air mass, with only small rainfall at the center and in the northwesterly air mass. The source of such heavy rainfall was naturally sought in the great humidity of the southerly warm air mass, which, on encountering the cold northwesterly air mass, ascended over the latter along the boundary surface between them, so that heavy precipitation was caused in the region of the northeasterly air mass. This action was superposed, on the one hand, by the orographic effect, resulting in an area of heavy rainfall along the southern mountain slope facing the Pacific Ocean, and, on the other hand, by the warm, humid southerly and southeasterly air, which, by crossing the central mountain range, could not descend the northern mountain slope because of the cold, humid northeasterly air vigorously ascending the northern slope, so that the southeasterly upper air current must have had a steeper ascending surface. Consequently, condensation in both the cold under currents and in the warm upper currents caused also heavy downpours along the northern mountain range.

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[14] E.g., Palmén, *Meteorol. Zeitschr.*, 1931, pp. 281–288.

Equivalent potential temperature, by M. Murase.—By plotting the values of equivalent potential temperature on the weather map the author could distinguish very clearly the boundary of the three air masses. In the proximity of the typhoon center the warm sector pushed itself northward, then northwestward, then westward, and at last southward, occupying a bay-shaped area on the north side of the typhoon center, and eventually occluded. The center of the typhoon passed along the distinct front of the southerly air current, as shown by the sudden change in the equivalent potential temperature. It was also shown that at first the equivalent potential temperature was cold in the upper level and warm at the ground, that is, there was stratification of so-called convective instability. Before the typhoon arrived, this condition changed and became stable, that is, on the summit of Mount Huzi (Fuji, 3800 m.), the equivalent potential temperature became higher than the value at the base stations. After passage of the typhoon, ordinary convective instability prevailed again. Thus it seems that convective instability is not a state of actual instability, but rather a state of normal fine weather in Japan, convective stability itself being a symptom of bad weather.

Vorticity and convergency, by N. Yamamoto and K. Takeda.—By calculating the vorticity and convergency from observed wind velocity, the authors obtained the distribution of vorticity in the typhoon area. Vorticity and convergency both decreased with time after September 20, which may have been due to the fact that the typhoon had already started to decay when it approached Japan Proper. The mean vorticity in the whole area was 5×10^{-5} per sec. and the mean ascending current, calculated from the convergency, was 2.5 cm. per sec. at a level of 1000 m. above sea level. Vorticity was largest in the northeast quadrant; at the typhoon center it was 1.8×10^{-3} per second, or in angular velocity 9.0×10^{-4} radian per sec., which is 13 times that of the earth's rotation. Vorticity decreased as the central distance increased.

World's record of lowest barometer observed at a land station, by T. Mizuno.—The author, who is Director of the Muroto Meteorological Observatory, used a barograph of Richard's type, and at the same time made eye observations every ten minutes with a standardized normal mercurial barometer when the typhoon center approached. He put back the pen of the recording barograph twice when it reached the bottom of the recording sheet, and then put it down once when it reached the top. He corrected the readings of the mercurial barometer in the ordinary way to zero temperature and standard gravity and, by means of them, made interpolational corrections to the barographic record, to which he had already made time corrections. Then he reduced the barometric height thus obtained to the M. S. L. and rigorously obtained 684.0 mm. Hg. as the lowest value at 5^{h} 10^{m} on the 21st. This is the world's lowest record value observed at an authentic land station.

General discussion, by S. Fujiwhara.—From the foregoing, it is clear that the typhoon was situated exactly on the boundary of the warm humid (tropical maritime) air mass and the cold (temperate) air masses, in which it is possible to distinguish the humid northeasterly (maritime) and the dry northwesterly (continental) air masses. The great difference in the heat and moisture content of these air masses was dissipated by the stirring action of the typhoon. That is to say, the typhoon was a sort of mechanism for relieving the accumulated energy in the form of potential inequality. As will be seen from the foregoing as well as from other data, vertical inequality of any kind can be the cause of rainfall on a small scale, such as showers, but not that on a large scale, such as typhoon rainfall. For the latter, only horizontal instability, the slightest of all instabilities, is responsible. Horizontal inequality first gives rise to phenomena at the surface of discontinuity, after which the generated kinetic energy converges into the typhoon center and builds up that tremendous whirl. It will also be remembered that on this occasion, at the earth's surface, the four typhoon centers relayed one another, so to speak, whereas in the upper atmosphere only one and the same center passed over the Japanese islands.

Concentration of Cl ions in rain water, by T. Asahina and T. Kita.

Luminous phenomena that accompanied the typhoon.

Descriptions of the typhoon from 38 meteorological stations.

High water caused by the typhoon, by K. Sekiguti, M. Kisima, R. Hirano, M. Yamaguti, and K. Hidaka.

Meteorological tide, by M. Nakano.

Local inspection, by numerous officials.

Damage caused by the typhoon.

List of publications on the Muroto typhoon.

Meteorological observations at all the observatories and stations before and during the typhoon.

Meteorological observations by ships at sea.

Upper air observations.

A list of past typhoons, with descriptions.

Description of the typhoon and the high tide of September 9–15, 1927.

Prediction of typhoon track by observations of the upper air current, by T. Otani.

A theory of the cyclone, anticyclone, monsoon, and thunderstorm, by H. Arakawa.

Application of Watanabe's term to explain the mechanism of a depression, by S. Fujiwhara.

High water accompanying the passage of a depression, by H. Arakawa and M. Yositake.

Tunami caused by the typhoon in Osaka Bay, with special reference to oscillation of the bay water mass, by K. Terada.

Damage to power transmission lines with respect to the salt content of typhoon air, by K. Terada.

On the wind velocity at Muroto during the passage of the typhoon, by S. Akamatu and N. Sinozaki.

On the tilting and pulsatory motion of the earth during the passage of the typhoon, by K. Wadati and M. Kisima.

Anomaly of rain water contents caused by salt-laden air, by E. Kurasige.

Another important report on the Muroto typhoon was issued by the Imperial Marine Observatory, Kôbe,[15] containing papers by Y. Horiguti, G. Okada, T. Sano, K. Hidaka, K. Koinuma, K. Tanabasi, Y. Matudaira, T. Taguti, and K. Tsukuda. T. Namekawa and S. Aoki, who made a special study of the Muroto typhoon, advanced the hypothesis[16] that it was composed of two circulating systems, the one the main typhoon with a central depth of 730 mm. Hg. throughout its passage over Japan, running along a regular parabolic path, and the other, the secondary typhoon, of small dimensions and a short life, but with a very intense tornadoic center, the lowest barometric indication of which was 684.0 mm.—a view opposed by Horiguti,[17] but supported by S.

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[15] *Umi to Sora (Sea and Sky)*, 14(1934):353, 367–414.

[16] *Mem. Coll. Sci., Kyoto Imp. Univ.*, ser. A, 19(1936).

[17] *Umi to Sora,* 16(1936):347–352.

Aoki[18] and S. Adati.[19] We would say that any asymmetrical vortex can be decomposed into two, three, or more symmetrical vortices, exactly as is done with an irregular oscillation which is decomposed into a number of regular oscillations by means of Fourier's analysis. However, seeing that the analysis is rather fictitious, the secondary, tertiary, or any smaller component vortices obtained by the above method must strictly be distinguished from actual secondaries.

Air current in typhoon.—T. Otani and H. Hatakeyama[20] statistically determined the distribution of air currents in typhoons in the layer up to 2000 m. above the ground by using data of pilot balloon ascensions. They found: (1) that an ascending motion exists in the central area within 500 km. of the central distance; (2) that a converging horizontal current exists in the layer, of 0 to 2000 m., in nearly all sections from the center to 1125 km. radius, except a small part in the top layer, 1500–2000 m. high and 875 km. distant from the center, the area of convergence nearly coinciding with the area of rainfall; and (3) that the horizontal current surrounding the center is not symmetrical, but is stronger in the southern and eastern parts of the typhoon area, so that the southwesterly current is strongest in middle altitude in typhoon areas in the temperate zone.

These results were proved also with respect to the Muroto typhoon. T. Otani[21] then proposed a method of predicting the further path of typhoons by using data of observations of upper air currents at two stations situated exactly opposite each other with respect to the typhoon center—a method very useful in routine work.

Front, air mass, and birthplace of typhoons.—T. Otani and K. Takeda[22] pointed out a peculiarity in typhoons that pass near Kwanto, Japan, accompanied by lines of discontinuity. They found that typhoons in this district invariably consist of three air masses: a warm maritime air from the south, a cold maritime air from the northeast, and a cold, continental air from the northwest. Three such air masses were also observed in the Muroto typhoon as shown above.

By using upper-air data obtained by balloons, kites, and aeroplanes, H. Arakawa[23] proved that, in the temperate zone, so far as the layer up to 3000 m. is concerned, fresh tropical maritime air occupies the south and east quadrants of typhoons, sometimes showing remarkable temperature inversions in it. In the north quadrant, however, there is a cold air mass with rather great lapse rates. He also constructed statistics and determined the two main tracks of typhoon passage in the Japanese Southern Ocean, the one lying in the direction east-southeast–west-northwest, passing between Saipan and Palau islands, and extending westward to the South China Sea, the other running along the Japanese arc southeast of it, from south of the Ryûkyû Islands to the east of Hokkaidô. These tracks, however, mark the boundary of the semipermanent high of Ogasawara, from which the northeasterly trades blow out on its southwest side and southwest monsoons blow out on its northwest side. As is already known,[24] typhoons are born in valleys of low pressure between two high pressures, the one the high of Ogasawara and the other the northward extension of the high of the Southern Hemisphere across the equator covering the Philippines and their vicinity. This was also ascertained by the Muroto typhoon, as already shown. This valley, the breeding place of typhoons, coincides with one of the tracks of typhoon passage—a view also supported by C. E. Deppermann.[25] T. Otani[26] statistically determined the region of typhoon birth. It lies between latitude 5°–20° north and east of 130° longitude. The eastern boundary has not yet been determined. The birthplace changes with the time of year, that is, in June and July it is most frequent around Truck Island, in August it shifts northward as far as Saipan Island, while in September it shifts farther northward, after which it returns southward. The track is also subject to seasonal variation, as is well known. There are, of course, many that take extraordinary paths. Otani divided these paths into five classes.

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[18] *Oyô Buturi* (Applied Physics), 5, pp. 410–413.

[19] *Umi to Sora*, 17(1937):490–495.

[20] *Jour. Meteorol. Soc. Japan*, 9(1931):710; 10(1932):282, 679; also *Geophys. Mag.*, May, 6:97.

[21] *Jour. Meteorol. Soc. Japan*, 13(1935):288–290.

[22] *Jour. Meteorol. Soc. Japan*, 12(1934):260.

[23] *Jour. Meteorol. Soc. Japan*, ser. 2, 14(1936):405–414; see also *Beitr. z. Phys. d. f. Atm.*, 24(1937):156–161.

[24] T. Okada, *Proc. 5th Pac. Sci. Cong.*, 1933, 3:1983.

As to the three air masses in a typhoon, M. Rodewald[27] considered his "Dreimassenecke" as the birthplace of typhoons. This view differs somewhat from our Japanese experience, as already explained. We discern three air masses, nearly always at the turning point of its track[28] and along its later course.[29] Rodewald suggested frequent generations of typhoons in years when the continental temperature runs high. H. Arakawa[30] compiled statistics and found a positive correlation, 0.60, between the frequency of typhoon generation in September and October and the mean air temperature at Shanghai. This accords with Rodewald's suggestion. As to the controversy on the warm sector between A. E. True and C. E. Deppermann,[31] we Japanese agree with the latter authority, so far as typhoon travel in lower latitudes is concerned. In Japan Proper and its vicinity we have a warm front, as very clearly shown in the foregoing study of the Muroto typhoon. Horiguti's opinion [32] on Philippine typhoons accords with Deppermann's ideas. S. Fujiwhara[33] worked out five factors for determining the course of a typhoon, and explained the contradiction which sometimes arises in the operation of these factors. S. Kato[34] described the symptoms of a typhoon as it approached Naha, Ryûkyû Island. K. Koimuma[35] pointed out the existence of layers in the atmosphere wherein the wind velocity becomes maximum in the case of a typhoon.

Generation of depressions.—From this paragraph to the end of the present note the status of the depression investigation is concerned. On the problem of cyclogenesis, there are three statistical investigations, one by R. Date[36] on the generation of depressions in the Japan Sea, one by T. Otani and S. Yamada[37] on the same in the southern part of the China Eastern Sea, and one by S. Syôno and H. Sakata[38] in Japan and its neighborhood. In the last-mentioned research we can recognize five types of cyclogenesis in the Far East. The first type, which is most marked in Mongolia and Manchuria, has the maximum generation twice a year, in May and October. The second type is most conspicuous in the Yangtze Valley and in the Eastern China Sea, generating most frequently in June. The third type is most striking in the Japan Sea, coming with greatest activity in winter (January). The fourth is the type in Japan Proper, its single maximum appearing in May. The fifth is the typhoon that comes from the southern ocean, visiting Japan most frequently in September. S. Fujiwhara[39] has pointed out the contrast in cyclogenesis between the east and west sides of the continents.

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[25] Manila Central Observatory, "Typhoons Originating in the China Sea," 1938.

[26] *Tenki to Kiko,* 4(1937):432–437, 551–556.

[27] *Meteorol. Zeitschg.,* 1936, p. 197.

[28] Arakawa, *Jour. Meteorol. Soc. Japan,* 15(1937):186. See also *Beitr. z. Phys. d. f. Atm.,* 24(1937):156–161.

[29] Otani and Terada, *Jour. Meteorol. Soc. Japan,* 12(1934):260.

[30] *Tenki to Kiko,* 5(1938).

[31] Manila Central Observatory (1937), "Wind and Rainfall Distribution in Selected Philippine Typhoons"; also, "Are There Warm Sectors in Philippine Typhoons?"

[32] *Umi to Sora,* 17(1937):340–346.

[33] *Tenki to Kiko,* 3(1936):397–399.

[34] *Tenki to Kiko,* 4(1937):236.

[35] *Umi to Sora,* 13(1933):352.

[36] Commemoration Volume of Professor Okada (Japanese), p. 108.

[37] *Jour. Meteorol. Soc. Japan,* 16(1938):255.

[38] *Sokukô Zihô,* 10(1939):25–32.

K. Koinuma[40] studied the evolution of the secondary depression, as when a mother depression encounters a mountain range, promontory, etc. He compiled statistics and drew conclusions regarding the accumulation and outflow of air on such occasions.

S. Sakuraba[41] theoretically investigated the problem of the conversion of a vertical circulation into a horizontal one.

Growth or development of depressions.—H. Arakawa[42] has shown, mathematically, that depressions and typhoons must reach their maximum intensity at the turning point on their track.

S. Fujiwhara[43] has shown good examples of quick development of cyclones by amalgamation. Y. Kobasi and K. Takase,[44] who attacked the problem of amalgamation, carried out statistical investigations, and obtained the following results:

1. Of the 107 depressions that appeared in 9 months, except in summer, 8 appeared alone and the remaining 99 appeared in twos or threes at the same time. Of these, 13 did not amalgamate; there were ambiguities regarding 15; and 71 amalgamated. That is to say, Japanese depressions have a tendency to amalgamate.

2. Of the amalgamated depressions, 80 per cent made further development of those which sucked in other smaller depressions, 96 per cent developed; of the nonamalgamated, 69 per cent developed; and of solitary depressions, 63 per cent developed. This shows that a Japanese depression has a tendency to develop and especially when it amalgamates others or when it makes amalgamation with others.

K. Koinuma and T. Sumita[45] have shown an example of a cyclone in Hokkaidô that quickly developed by receiving a warm southerly humid air mass, the inflow of which had been hindered by Japanese mountain ranges when the cyclone was in the Japan Sea.

S. Oma[46] statistically studied the time and space distribution of the growth of depressions in Japan and vicinity.

Motion of air in a cyclonic depression.—The effect of eddy viscosity on cyclonic motion in the lower layer of the atmosphere was theoretically treated, independently by D. Nisimura,[47] Y. Isimaru[48] and K. Koinuma.[49] H. Arakawa[50] also dealt with this problem, assuming a high temperature at the center of the cyclone.

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[39] Read before meeting of Meteorol. Soc. Japan, June 9, 1939.

[40] *Umi to Sora*, 17(1937):434–439.

[41] *Jour. Meteorol. Soc. Japan*, 15(1937):550.

[42] *Jour. Meteorol. Soc. Japan*, 14(1936): No. 8; see also *ibid.*, 15:186.

[43] *Geophys. Mag.*, 11(1937): 41.

[44] *Jour. Meteorol. Soc. Japan*, 15(1937):232.

[45] *Umi to Sora*, 15(1935):411.

[46] Read before meeting of Meteorol. Soc. Japan, May 26, 1939.

[47] *Jour. Meteorol. Soc. Japan*, 9(1931):429, 509; 10(1932):113.

[48] *Jour. Meteorol. Soc. Japan*, 9(1931):556; 11:306–310; 11:299.

[49] *Jour. Meteorol. Soc. Japan*, 9(1931):621.

[50] *Geophys. Mag.*, 10(1936):43.

Structure of depressions.—The distribution of meteorological elements in depressions was statistically studied by S. Takaya.[51] One of the important results is that, in Japan and its vicinity, an average depression is not symmetrical around its center, but asymmetrical with a warm air mass in the south, east, and northeast quadrants and with cold air in the northwest, west, and southwest quadrants. Otani[52] pointed out that winter depressions in Japan and its neighborhood nearly always consist of two air currents, while depressions in other seasons are mostly composed of three currents, especially marked in typhoons. He also adds that depressions in Japan have a larger warm sector than those in Europe, and that when a depression moves in a direction within the warm sector, then both the two lines of discontinuity that border the warm sector become cold fronts. Thus a depression has no warm front, notwithstanding its very wide warm sector.

By analyzing a cyclone that passed Hokkaidô on January 22, 1935, K. Koinuma and T. Sumita[53] observed also the three air masses, namely, the northeasterly, northwesterly, and southerly, besides which they also observed a warm and dry air mass at the center of the cyclone, which they regarded as being subjected to pseudo-adiabatic descent by orographic föhn action. Deriving energy from these air masses, especially from the southerly warm humid air, the cyclone developed very rapidly.

H. Futi, S. Tazima, and N. Murase,[54] who analyzed a cyclone that passed the Tusima Straits, also observed the three air masses. They also observed the occlusion and backbending of a cold front, which is rather a rare atmospheric phenomenon in the Far East.

According to S. Sakuraba,[55] it is possible, as in the traveling cyclone and anticyclone, to distinguish high and cold stationary or semipermanent cyclonic systems from a low and warm cyclonic system and a low and cold anticyclonic system. For example, the continental high, from which the winter monsoon blows, belongs to the low and cold type, etc.

Travel of depression.—S. Fujiwhara, T. Otani, and A. Noguti[56] worked out the resultant pressure deviation under lunar influence by superposing the pressure terms that vary respectively with periods of synodical, tropical, and nodical lunar months for every meteorological station in which periodic analysis had so far been made. They entered the resultant pressure deviation due to lunar influence in weather charts, and found that during some consecutive days the actual trend of isobars and the general feature of the pressure distribution are quite similar to those of lunar influence, although the amplitudes of change and variation in the latter are about one-tenth those of the former. This similarity, however, exists not always, but intermittently. Moreover they found that some typhoon centers were guided by the minima of the lunar influence throughout its passage through Japan and vicinity. About 70 per cent of all typhoons examined were proved to have this characteristic.

H. Arakawa,[57] who made a hydrodynamic study of the center of vorticity, found that when the vorticity is distributed symmetrically around the center, no emigration of center occurs, but that when the distribution is asymmetrical the center has a tendency to travel—another proof of what H. Jeffreys had already found.

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[51] *Rept. Imp. Marine Obs. Kôbe,* No. 35 (1930).

[52] *Sokkô Zihô,* 6 (1935) :157.

[53] *Umi to Sora,* 15 (1935) :411.

[54] *Sokkô Zihô,* 8 (1937) :327.

[55] *Jour. Meteorol. Soc. Japan,* 15 (1937) :194.

[56] *Jour. Meteorol. Soc. Japan,* 8:221, 419; 9:152.

[57] *Geophys. Mag.,* 4 (1931) :117.

M. Murase,[58] who obtained statistics on the north component of the traveling velocity of the depression in Japan and its vicinity, found that it has the first maximum in autumn, the first minimum in winter, the second maximum in spring, and the second minimum in summer. The component velocity is small in the daytime, but large at night.

K. Koinuma and T. Sumita[59] analyzed a depression that passed Hokkaidô on January 22, 1935, and found that the main cyclone decayed in the Japan Sea and that the first secondary, which had evolved west of Hokkaidô in front of the main, developed vigorously and replaced the main. It then proceeded northeasterly, but instead of landing on Hokkaidô it gradually began to decay, while the second secondary that developed near Sapporo replaced the first and moved eastward. It then decayed, when the third secondary succeeded the second and moved away across the Okhotsk Sea. Such behavior of a traveling depression on crossing land was also recognized on the occasion of the Muroto typhoon, the mechanism of which has already been explained by T. Kobayasi.[60] The authors also noticed that, in accordance with Palmén's[61] opinion, the second secondary moved in the direction of the isobars in the warm sector.

H. Futi[62] pointed out that depressions, especially typhoons, move along the isotherms (of average temperature for 24 hours) in the ground layer of the atmosphere, the reason being that it rests on the same basis as the method of forecasting the motion of a depression center by using the isobars at a level of 3000 or 4000 m. above sea level, which last method has been well developed for practical use in Japan since 1919.[63] A similar principle was also adopted recently in Germany by F. Baur[64] by drawing isobars at levels of 5000 Berk. H. Arakawa,[65] upon examining the applicability of the method of kinematical analysis of Angervo and Pettersen to a Japanese weather chart, found the method to be very useful in certain cases of developing cyclones. He also proposed a simple method of drawing future isobars, based on the same principle as that of the authors named above. M. Kozima and Z. San'nokura,[66] who also discussed the same problem, showed the degree of accuracy attainable by the method as applied to Japan.

N. Saitô[67] drew up statistics on the relation between the traveling velocity of depressions and the motion of cirrus. He found a high correlation existing between them, and proposed the formula $v = 0.94c - 17.8$ m/sec., where v denotes the velocity of the depression center and c the speed of the cirrus. The cloud observation on which this study is based was made at Mera, near Tokyo, by Y. Ishimaru and others.[68]

Orographic, cyclonic, and advective precipitation.—D. Nishimura[69] conducted elaborate researches on Japanese rainfall, in which he described the rainfall peculiarities of every district in Japan with respect to the position and path of depressions, cyclones, and typhoons. Although it is not possible to discuss here his investigation in detail, there is no doubt that the work is important in connection with forecasting the amount of rainfall in Japan. He also explained the mechanism of orographic rainfall of the second type, that is, rainfall along river sides. K. Sone and K. Iida,[70] who attacked the same problem, confirmed Nishimura's results.

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[58] Okada Commemoration Volume (Japanese) (1932), pp. 309–316.

[59] *Umi to Sora,* 15(1935):411.

[60] *Quart. Jour. Roy. Meteorol. Soc.,* 48(1922):168–183.

[61] *Meteorol. Zeitschr.,* (1931):281–288.

[62] *Jour. Meteorol. Soc. Japan,* 13(1935):555–564.

[63] S. Fujiwhara and K. Sekiguti, *Jour. Meteorol. Soc. Japan,* 38(1919):254–259.

[64] *Meteorol. Zeitschr.,* 53(1936):237–247.

[65] *Jour. Meteorol. Soc. Japan,* 13(1935):260–274.

[66] *Jour. Meteorol. Soc. Japan,* 14(1936):484–487.

[67] *Jour. Meteorol. Soc. Japan,* 15(1937):176–179.

[68] M. Watanabe, Y. Ishimaru, and K. Yosinari, "Report on cloud observation," Centr. Meteorol. Obs., Tokyo, 1930.

[69] *Jour. Meteorol. Soc. Japan,* 8(1930):109, 183; 9(1931):409, 487, 657.

In Japan there sometimes occurs very heavy rainfall in the warm season, accompanied by floods and severe damage. Such rainfall is caused by a typhoon on the one hand and by southerly air currents on the other. For the latter, the name "advective rainfall" has been in use in Japan since 1922.[71] Many investigations were made in those days, the general view being that the rainfall must be caused by ascending southerly air currents along a sliding surface. Since, however, the amount of rainfall is tremendous, being frequently accompanied by thunder showers, some additional action must be in operation. For this, S. Takayama[72] considered mechanical vortices with horizontal axes along the sliding surface. D. Nukiyama[73] assumed an instability, due to pushing in of the southerly moist warm air under the westerly dry cold air. In a southerly position, the two currents are without condensation and can remain in stable equilibrium, but should the warm air be pushed farther north beyond a certain limit, their stratification then will become unstable and condensation must set in. Recently, serious damage by rainfalls of this type have so often occurred that a number of enthusiastic studies in this phenomenon were worked out from a new point of view. K. Koinuma[74] studied the one that occurred on June 26–29, 1935. He pointed out that the rain area advanced east with cold westerlies along the earth's surface. T. Otani and K. Sone,[75] who investigated the one that occurred in Kwantô on September 22–25, 1935, pointed out that, on the south side of the sliding surface, the potential equivalent temperature was between 345° and 355°A, while on its north side, it was between 315° and 327°A. Y. Horiguti's discussion[76] on the possibility of forecasting this rainfall was rather pessimistic in tone. He believed, however, that on the rainfall being caused by the southerlies against cold northerlies, there is some possibility of forecasting it. T. Sano[77] reported on one that visited Kôbe on July 3–5, 1938, which caused landslides that crushed thousands of houses and buried parts of the city with sand as much as 3 to 4 meters over a wide area. At Rokko, the total rainfall in 3 days amounted to 615.8 mm. H. Arakawa[78] also reported on rainfall in the Kwansai and Kwantô districts from June 28 to July 5. In these 9 days, 758 mm. of rainfall was measured at Numadu. As indicated by upper observations, the main cause of such enormous rainfall was the southerly warm and moist air current that climbed up against the cold air mass along the sliding surface. According to his opinion, the rainfall must have been accentuated by the instability that came about in the warm air as the result of the two processes operating, the one due to the general ascension of the layer as a whole and the other to the convective instability due to the heat given up to air by condensation of water vapor in the lower part of the layer when the whole layer was elevated. This mechanism was first suggested by Sir Napier Shaw,[79] and studied recently by C. G. Rossby.[80] To the present author, Arakawa's theory seems plausible, while Nukiyama's old theory, which is also sound, will become more practicable when the idea of condensation liability has to be invoked. The great westerlies in middle latitudes at heights exceeding 3000 or 4000 m. is dry and of high potential temperature, as is well known. Warm, southerly moist air can creep in under the great westerlies, maintaining stable equilibrium, so long as the former has no condensation. When, however, condensation sets in by some mechanism, such as that of the southerlies encountering a land or a mountain or a cold air mass, by which ascending motion is forced, then stability between the upper westerlies can hold no longer, and transposition of air masses of the upper and lower layers must occur on a large scale, resulting in thunder showers and heavy downpours.

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[70] *Jour. Meteorol. Soc. Japan,* 11(1934):633.

[71] S. Fujiwhara, *Jour. Meteorol. Soc. Japan,* 41(1922):289–294.

[72] *Kôbe Dokusyo Kwaiho,* No. 1(1919).

[73] *Umi to Sora,* 2(1922):88.

[74] *Uni to Sora,* 2(1922):88.

[75] *Jour. Meteorol. Soc. Japan,* 14(1936): 221–235.

[76] *Umi to Sora,* 15(1935):291–292.

[77] *Umi to Sora,* 17(1938):264–275.

[78] *Tenki to Kikô,* 5(1938):313–317; see also *Jour. Met. Soc. Japan,* 17(1939):7–19.

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[79] *Forecasting Weather,* 2d ed. (1923), p. 242.

[80] "Thermodynamics Applied to Air Mass Analysis," Mass. Inst. Tech. Meteorol. Papers, Vol. I (1932), No. 3.

CLIMATOLOGICAL DATA ON THE PACIFIC OCEAN

By H. Keyser

If climatological data are to be of value for science, shipping, and air navigation, the following conditions must be satisfied:

1. The observations must extend over a long period of time.
2. The number of observations must be large. Although this condition may seldom be satisfied in marine meteorology, the number of observations on which means are based must be known.
3. The observations must be reliable.

The last-named condition may appear obvious; but we ask whether everyone is aware that in principle the best observations of wind, pressure, and temperature are obtained from the oceans? Observations of these elements made on shore or on islands may be erroneous on account of the effect of topography and heating of the land surface. Of course the same degree of accuracy cannot be ascribed to all ships' observations. Therefore in working up observations made on shipboard it is necessary to separate the good from the bad.

All observations at present available for use in marine climatology go back, for their beginnings, to the maritime conference held at Brussels in 1853—a conference which was due in large part to the diligence and foresight of an eminent citizen of the United States, M. F. Maury.

The only available meteorological charts for the Pacific, taken as a whole, are the Pilot Charts published by the Hydrographic Office of the United States Navy Department, Washington, from data supplied in part by the Weather Bureau. These are published monthly for the North Pacific, quarterly for the South Pacific.[1] I think that even the Hydrographic Office and the Weather Bureau will admit that these charts do not fit all requirements.

Consequently, the Koninklijk Nederlandsch Meteorologisch Instituut learned with much pleasure of the approval by the Fourth Pacific Science Congress, 1929, of the resolution[2] proposed by Messrs. E. van Everdingen and G. Schott, which emphasizes the desirability of active coöperation in developing the practical and scientific aspects of oceanography and meteorology.

The Netherlands Institute, which at that time had finished a reprint of its atlases of the Indian Ocean and the last quarter of its atlas of the Atlantic Ocean, undertook the compilation of an atlas of the China Seas, for which numerous observations were available, and which would be of much interest to Netherlands shipping. This publication, K. N. M. I. No. 115,[3] is known to the members of the Sixth Pacific Science Congress.

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[1] I do not overlook the *Meteorological Charts for the World*, published by the Hydrographer of the Admiralty, London, 1928; but, though interesting, they are only quarterly charts, and so are inadequate for profound studies. Neither do I forget partial data and contributions. Among these I would mention especially the Current Charts, and the article, "The 1910 to 1937 Survey of the Currents of the South Pacific Ocean," by E. W. Barlow, in *Marine Observer*, 1938; also, *Geographie des Indischen und Stillen Ozeans*, by G. Schott, 1935.

[2] Resolution 15: "Whereas, it is the opinion of the Fourth Pacific Science Congress that the collection and critical examination of all existing surface data relating to the Pacific Ocean, with a view to their utilization for economic and scientific purposes, is indispensable for the solution of the problem of the circulation of the oceans, and for many other purposes;

"Resolved: (*a*) That all institutions possessing observations be asked to put these at the disposal of a central office to be chosen after deliberation by the Chairman of the International Committee on the Oceanography of the Pacific and the Chairman of the International Meteorological Committee."

[3] *Oceanographic and Meteorological Observations in the China Seas and in the Western Part of the North Pacific Ocean.*

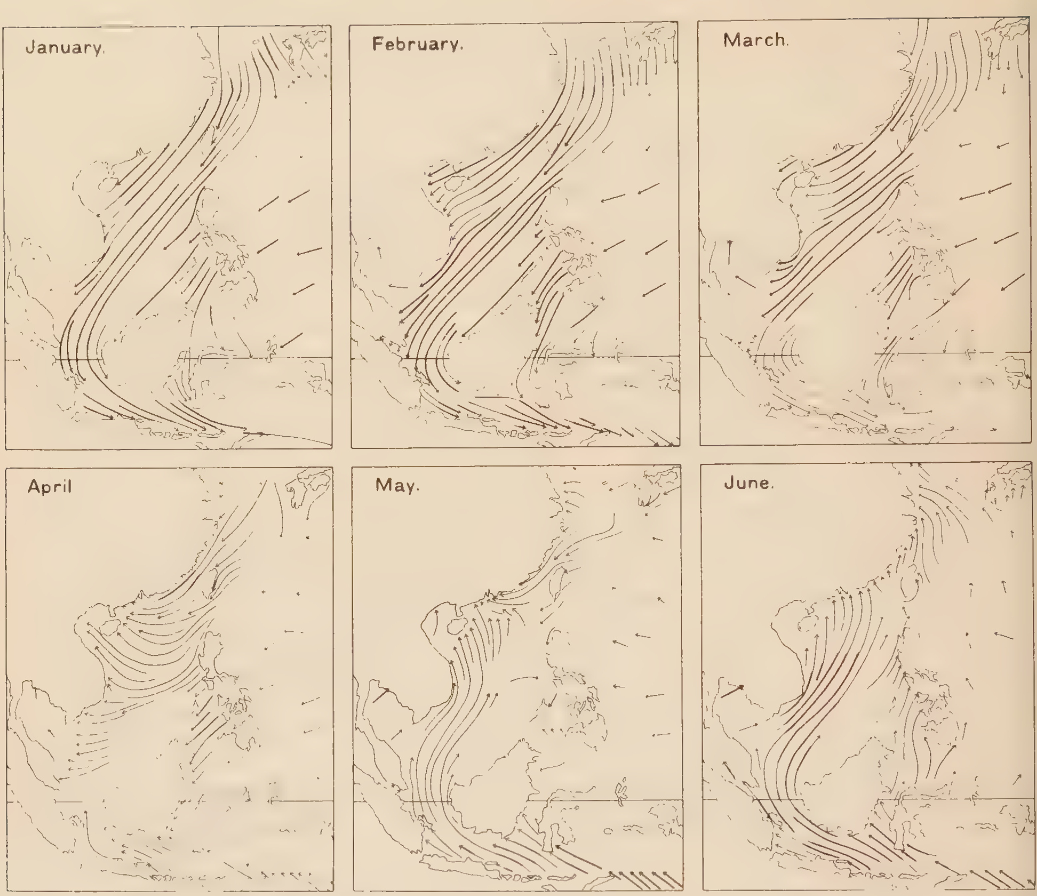

Fig. 1. *a*. Stream lines of the general air circulation over the China Seas, by months. Heavy lines indicate a "stability" of 75 per cent and over. (Reproduced from publication K. N. M. I. No. 115, "Oceanographic and Meteorological Observations in the China Seas," omitting figures showing force of air circulation.) *a*. January–June. *b*. July–December.

However, in order to support the statement made in the second paragraph above, the chartlets "Stream Lines of the General Air Circulation" included in the publication mentioned are reproduced here as figures 1, *a* and *b*. In my opinion no better argument can be cited for the value of marine observations than these drawings, which show the regular manner in which the change of monsoons takes place.

ATLAS OF AUSTRALIAN WATERS

The kind appreciation shown by both science and shipping with regard to the atlas of the China Seas has prompted the Netherlands Institute to begin the preparation of an atlas of the region 0°–50° south latitude, 100°–180° east longitude. This region adjoins that covered by the atlas of the China Seas, and the atlas planned is intended to be published in the same form.

International coöperation was again asked for, in order to supplement the data derived from observations made on Netherlands ships (about 300,000 sets of observations), because there are several areas for which the Netherlands material is scanty. The atlas of the China Seas contains observations

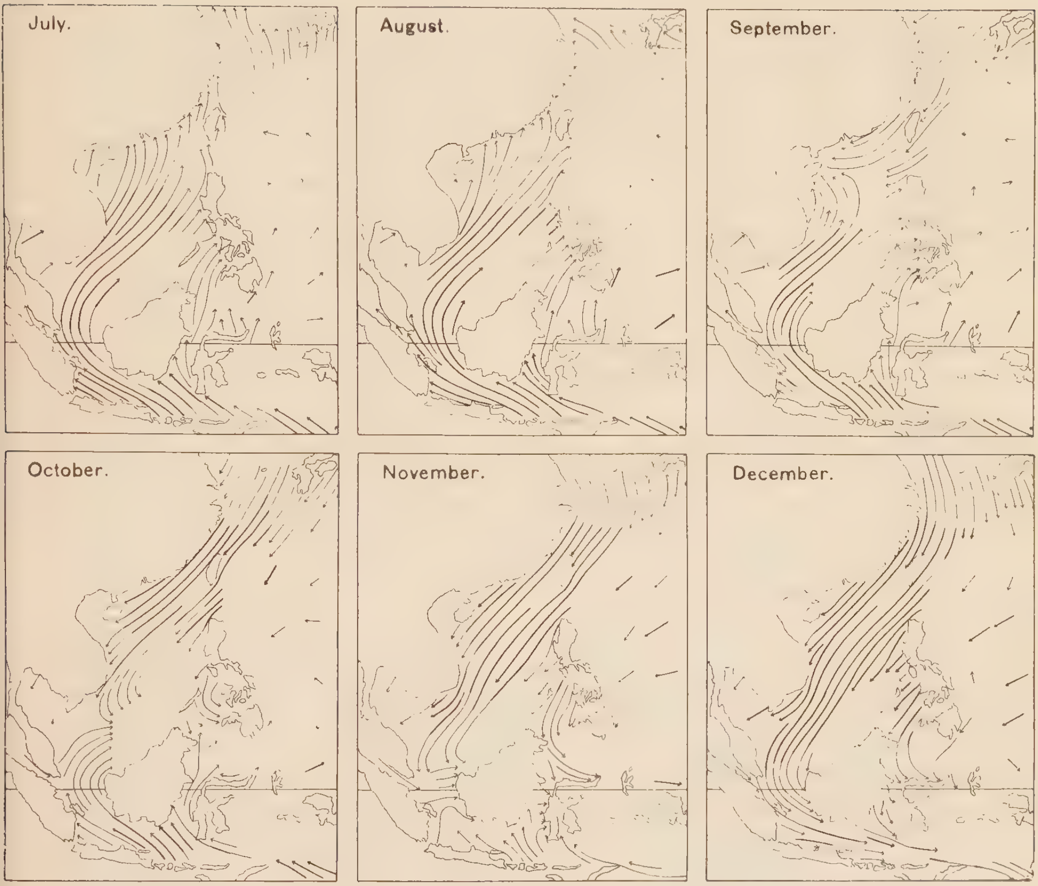
July. August. September. October. November. December.

Fig. 1. *b*. Stream lines of the general air circulation over the China Seas, by months. Heavy lines indicate a "stability" of 75 per cent and over. (Reproduced from publication K. N. M. I. No. 115, "Oceanographic and Meteorological Observations in the China Seas," omitting figures showing force of air circulation.) *a*. January–June. *b*. July–December.

from 1910 and later years. For the new atlas of Australian waters all observations from as far back as 1855 will be used; thus including observations from sailing ships on tracks no longer used by steamers.

We are pleased to report that the coöperation obtained will be greater than received before. The Meteorological Office in London has assisted by sending 175,000 punch cards of sets of observations and a quantity of current data. The Office National in Paris has placed at our disposal all available log books, from which about 22,000 sets of observations have been extracted. The Weather Bureau in Washington has lent 35,000 punched weather observations. The Hydrographic Office in Washington has tabulated from its Hollerith cards 4500 sea-surface temperatures and current drifts. The Deutsche Seewarte in Hamburg will place at our disposal all available log books. A thousand have already been received and extracted. The Commonwealth Meteorologist at Melbourne has sent a quantity of data for the Tasman Sea, and we hope to receive from the same office new charts of tropical cyclones.

At present it is impossible to state with any certainty the date at which the planned atlas will be published. The large amount of work involved in extracting the German log books will retard publication greatly, but the profits of international coöperation will outweigh this disadvantage, especially because many of the German observations were made in the area northeast of Australia, from which few other observations are available.

Even after the observations are extracted from the German log books, there will remain a great deal of work to be done: punching the observations, tabulating and recording the results, separately for the different nationalities, verification of the results, drafting and completion of the charting; so that approximately four years will elapse before the atlas will be ready.

I may remark here that all data of Netherlands, British, French, and German origin incorporated in the planned atlas relate to observations made six times daily at fixed hours local time.[4]

THE SYSTEM OF PUNCH CARDS AND CLIMATOLOGY

By this time the Hollerith and Powers system is generally known; we can therefore refrain from expatiating on the system itself. The system was introduced for marine observations first by the Meteorological Office in London in 1920; the Netherlands Institute adopted it in 1923; and now it is used by several institutes. At present, 4,000,000 sets of Netherlands ships' observations have been punched, and within a few years all observations, going back as far as 1855, will be extracted on punch cards.

What we wish to stress here is the fact that however complete atlases and other compilations of data may be, nevertheless it is impossible to record in them all the particulars that can be furnished by the punch cards. Charts of wind roses portray frequencies of directions and force of winds, current roses depict frequencies of directions and strength of currents. Some tables may be incorporated, for example those of daily range of pressure, such as were inserted in the atlas of the China Seas for the use of navigation. But in addition to all this the punch cards can provide further information too extensive to publish; for example, daily range of other elements, means by decades, individually observed elements arranged according to time or position, and so forth. All this information may occasionally be of immense value to climatologists, and therefore climatologists will do well to keep abreast of the information that can be afforded by the observations recorded on punch cards.[5]

PRESSURE DATA FROM THE CHINA SEAS

While the atlas of the China Seas was in preparation, a thorough investigation was made of the pressure data derived from observations made in that region, especially for the purpose of testing the accuracy of the data included in the pressure charts of the atlas and for the purpose of an investigation of typhoons. The results obtained are published in an appendix to a treatise on typhoons that is now in print.[6] The reader is referred to this treatise for full details; but some results are given here.

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[4] This remark is made on account of the following paragraph contained in the article, "Progress in Compiling and Summarizing Ships' Weather Observations," by I. R. Tannehill, in *Transactions of the American Geophysical Union*, 1938, Pt. 1, p. 152: "There is one noteworthy deficiency in the world-picture shown in these (U. S. American) charts. Practically all of the observations were taken at Greenwich mean noon, hence the local time of day varies with the longitude and there is a resultant diurnal variation which can not be evaluated with complete satisfaction. Since the diurnal variation of meteorological elements is not large over the oceans, this deficiency is not so important as would be the case with similar charts of continental conditions. In more recent years ships' weather observations have been taken regularly at other hours. When sufficient numbers of these observations at other hours are accumulated it will be possible to determine the character of the diurnal variation of the several elements."

[5] To prevent misunderstanding it should be stated that requests for information from punch cards can be complied with by the Netherlands Institute only after all observations have been punched, which will probably be in another two years.

Formulas in Fourier series of daily range of pressure.—It may be of interest to mention the accuracy of the averages used in computing these formulas, which are based on ships' observations made six times daily in four Marsden squares.

TABLE 1

PROBABLE ERROR IN MB. OF THE MEANS AT THE FIXED HOURS OF OBSERVATIONS USED IN COMPUTING THE FORMULAS OF DAILY RANGE

(Figures in parentheses give the total number of observations for all six hours of observation)

	Latitude	Longitude	January	July
10° square 96^{c+d}	30°–25° N	120°–130° E	0.21 mb. (1680)	0.17 mb. (1540)
10° square 97	26°–20° N	110°–120° E	0.15 mb. (2434)	0.13 mb. (2526)
10° square 61	20°–10° N	110°–120° E	0.09 mb. (2627)	0.09 mb. (3430)
10° square 26^{b+d}	10°–0° N	105°–110° E	0.07 mb. (2133)	0.05 mb. (2357)

Reliability of marine mercurial barometer readings.—From several investigations made in The Netherlands it may be assumed that the "probable" error of a single observation (due to incorrect reading and deficiencies of corrections applied) is smaller than 0.4 mb. in the tropics, 0.7 mb. outside the tropics.

Deviations from normal pressure.—These have also been thoroughly investigated both for land stations and for observations made on board moving ships, separately for each month.

The "probable" amount of deviation of a monthly mean from monthly normal pressure ranges from 0.47 mb. at the equator to 1.12 mb. in latitude 33° north (averages for 12 months). It is shown that deviations of this amount occur even if *no* typhoons come within reach of the station during the month under consideration.

The "probable" amount of deviation of pressure from the monthly normal on an actual day of observation, if no typhoon is present, amounts to 1.1 mb. at the equator, 2 to 4 mb. in latitude 30° north. These results were published in a table in the atlas, but I would state here that an excellent agreement was obtained between the values computed for land stations and those from ships' observations made in the same latitude.

Equivalence between ships' observations and observations made at land stations.—The average derived from 17,234 ships' observations in the neighborhood of land stations proved to be 0.15 mb. higher than the average for these stations (all months). We ascribe this fact to the constricted tube of the marine mercurial barometer. For the separate months the differences in averages are much larger, but this circumstance could be explained, in part, by local pressure gradients. Another reason may be the difference in period to which the land and ships' observations refer. For some other stations, however, it seems doubtful that the station data are fully trustworthy. They may be influenced by pressure and suction effects of the wind under special orographic conditions. I would give as an example the difference (a–b) between average pressure from ships' observations in the neighborhood of Zamboanga (*a*) and mean pressure at sea level at Zamboanga, in millibars, period 1917–1930, reduced to the period 1910–1930 (*b*) (figures in parentheses give number of observations).

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[6] Statistics relating to typhoons from about 3300 Netherlands ships' observations, 1910–1935. K. M. N. I. No. 119, De Bilt, 1939.

TABLE 2

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
+2.3 (24)	+1.6 (22)	+0.9 (33)	+1.7 (32)	+0.9 (33)	+1.1 (40)	+0.8 (27)	+0.7 (28)	+0.7 (22)	+0.4 (32)	+1.2 (21)	+1.2 (38)	+1.1 (352)

These ships' observations have been corrected for index, temperature, and gravity, and are reduced to sea level.

However, if the same ships' observations are corrected individually also for (1) daily range, (2) deviation of monthly mean for the actual year of observation from the normal, and (3) deviation of the daily mean for the actual day of observation from the monthy mean (Manila date), then the following differences are obtained:

TABLE 3

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
+1.1	+1.3	+1.2	+1.5	+1.2	+1.3	+1.2	+1.3	+0.8	+0.5*	+1.1	+1.2	+1.2

* Influenced by typhoons.

From this we may conclude that the normal values for Zamboanga are probably 1.2 mb. too low.

ATMOSPHERIC CURRENTS IN FRENCH OCEANIA

By J. L. Giovannelli

In an article published in the *Annales de Physique du Globe de la France d'Outre-Mer*[1] we have summarized, though in rather statistical form, the data supplied by the 840 aerologic soundings effected in French Oceania during the period 1934–1937. These data showed that above Tahiti there are two principal atmospheric currents: the trade, and the antitrade.[2] They overlie each other in such a manner that a vertical section of the atmosphere through Papeete shows the following strata:

1. Between the ground and 1500 meters on the average, a *disturbed zone* in which the direction and force of the wind are in large measure affected by relief.
2. The *trade wind*, the upper limit of which shows very large fluctuations about a mean elevation of 3000 meters.
3. A *zone of transition*, the thickness of which is equally variable. At times it may disappear completely.
4. The *antitrade*, the characteristics of which in our region are as yet imperfectly known.

The purpose of the present note is to attempt to define more precisely the respective importance of these currents. We shall make use of the data obtained in 1938, and study the annual variations of the currents as they appear in the observations made during the period 1934–1938. The number of soundings distributed over the five years of almost continuous observation is rather large. We have, namely, a total of 1091 soundings, among which

932 (85 per cent) have reached or exceeded an elevation of 2,000 meters
627 (57 per cent) have reached or exceeded an elevation of 4,000 meters
456 (42 per cent) have reached or exceeded an elevation of 6,000 meters
323 (30 per cent) have reached or exceeded an elevation of 8,000 meters
203 (19 per cent) have reached or exceeded an elevation of 10,000 meters

Velocities of the Free-Air Currents

Velocity of the winds has first been computed by using exclusively the data furnished by the soundings that reached a height of 10,000 meters. Then, for the lower layers of the atmosphere, the data from the 627 soundings reaching or exceeding 4000 meters were used. The values so obtained are shown in the accompanying table 1, and are used in drawing the corresponding curves of figure 1. The curves reproduced there have, in general, a certain similarity of form: on the whole, one finds in every month the same sequence of characteristics from the ground upward. This sequence may be summarized, in general terms, as follows:

1. *Increasing velocities* between the ground and a certain altitude, z_1, that varies with the season.
2. Between z_1 and a second recognizable altitude, z_2, a layer of *decreasing or very low velocities*, the thickness of which is also variable. In it there takes place a rotation of 90° to 180° in the direction of the winds.
3. A layer of *increasing velocities* between z_2 and 10,000 meters. The increase in velocity is much more marked during the dry season than in January, February, or March. In the latter season, indeed, it is sometimes not observed at all.

Because of the paucity of the data we have at our disposal at present, and

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[1] No. 28, August, 1938, pp. 102–105.

[2] Though Tahiti lies in 18° south latitude, the direction from which the wind that we here call "trade" blows is not southeast, but east to northeast. Cf. the article cited in note 1, p. 104.

TABLE 1

Mean Velocity of Upper-Air Winds (1934–1938) at Papeete, Tahiti, in Kilometers per Hour

Altitude (Meters)	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
A. According to the results of 203 soundings reaching or exceeding 10,000 meters													
1,000	18	11	17	10	11	10	22	14	11	14	12	13	14
2,000	22	14	10	22	18	13	25	21	18	17	14	20	18
3,000	24	15	7	20	21	17	21	32	21	19	20	22	20
4,000	25	18	18	14	15	14	18	25	25	21	18	25	19
5,000	23	16	17	19	18	22	20	24	20	20	25	20	21
6,000	16	10	21	24	28	28	25	32	17	25	28	26	23
7,000	23	15	24	26	30	32	32	40	21	30	36	30	28
8,000	25	18	26	32	36	39	36	42	32	34	40	32	33
9,000	28	21	25	36	40	45	40	50	36	42	42	45	37
10,000	35	25	26	40	47	54	45	55	40	45	46	50	42
B. According to the results of 627 soundings reaching or exceeding 4000 meters													
500	14	14	15	10	8	9	11	12	9	10	11	11	11
1,000	17	15	16	11	10	12	17	13	11	12	14	13	13
1,500	20	18	18	17	12	14	22	17	14	15	15	15	17
2,000	22	21	21	25	16	15	24	21	16	19	16	20	20
2,500	23	22	22	22	17	16	18	25	18	22	20	21	21
3,000	25	23	23	20	17	17	16	32	20	21	23	22	22
3,500	26	25	24	17	16	15	15	29	21	22	24	23	21
4,000	28	25	25	15	15	14	15	22	22	23	26	24	21

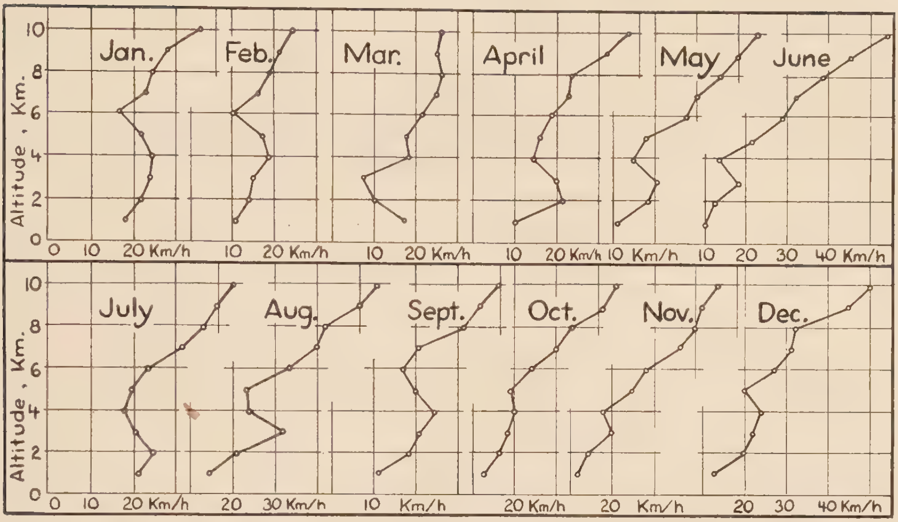

Fig. 1. Upper air currents at Papeete, Tahiti, according to 203 soundings reaching an elevation of 10 km. Mean velocities in km. per hr.

especially because at very high altitudes the measurements are inevitably inexact, it is very difficult to say with certainty how the velocity of the wind varies above 10,000 meters. From a few soundings in the course of which we have been able to follow the pilot balloons to still greater heights, it appears that at a certain altitude the velocity of the wind *attains a maximum and rapidly decreases* above it.

Table 2 gives for each altitude between 1000 and 10,000 meters the frequencies of wind velocities classified into five groups: 0–5, 6–25, 26–50, 51–75, and above 75 km. per hour. It will be noted that velocities in excess of 50 km. per hour are very rare, if not exceptional, below 6000 meters; but that they become more and more frequent as one goes upward. They form 60 per cent of the observations at 10,000 meters. At this height the winds of very high velocity, above 75 km. per hour, are nevertheless very rare, constituting scarcely 10 per cent of the total number of observations.

VARIATION IN VELOCITY OF THE WINDS WITH DIRECTION

It is known that the changes in direction of the free-air winds with elevation are associated with significant changes in velocity. When the direction of the wind changes, there is a progressive slowing down that is sometimes rather rapid. The clearest changes in direction that we have observed at Tahiti appear in the zone z_1–z_2 mentioned above. This layer therefore separates two currents that always have different, often opposite, directions; and it is in order to emphasize the role that this layer appears to play as intermediary between the currents above and below it that we have recently named it "transitional" zone or stratum. This zone is somewhat analogous to "that discovered by Hergesell, and by him named zone of mixing or of transition."[3]

The following conclusions can be drawn from table 2:

1. The winds from north, northeast, east, and southeast, although they do not display the same frequencies of intensity or duration, are subject to simi-

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[3] Cited by H. Ficker, "Richtung von Wind und Wolken auf Teneriffa," according to the English translation published in *Monthly Weather Review*, 1926, p. 466.

TABLE 2

Frequency of Directions and Velocities of Upper-Air Winds at Papeete (Tahiti), 1934 to 1938

(*a*, velocities of 5 km/hr. and less; *b*, velocities between 6 and 25 km/hr.; *c*, velocities between 26 and 50 km/hr.; *d*, velocities between 51 and 75 km/hr.; *e*, velocities in excess of 75 km/hr. Numbers of observations reduced to proportional parts of 1,000)

A. At 1,000 meters

	N	NE	E	SE	S	SW	W	NW	Sum	N	NE	E	SE	S	SW	W	NW	Sum
	January–February–March									April–May–June								
a	..	..	..	..	..	..	..	..	123	..	..	..	..	..	..	..	..	192
b	30	130	141	30	15	30	10	25	411	33	104	119	19	7	37	37	30	386
c	15	125	191	0	0	0	0	0	331	11	189	126	0	0	7	7	4	344
d	10	60	60	0	0	0	0	0	130	11	48	15	0	0	0	0	0	74
e	0	5	10	0	0	0	0	0	15	0	4	0	0	0	0	0	0	4
Sum	55	320	402	30	15	30	10	25	1000	55	345	250	19	7	44	44	34	1000
	July–August–September									October–November–December								
a	..	..	..	..	..	..	..	..	128	..	..	..	..	..	..	..	..	120
b	42	148	193	19	11	26	26	42	507	30	153	201	29	16	32	48	29	538
c	8	136	148	4	0	8	4	4	312	3	143	114	6	0	16	13	6	301
d	0	30	15	0	0	0	0	0	45	0	29	9	0	0	0	0	0	38
e	0	8	0	0	0	0	0	0	8	0	3	0	0	0	0	0	0	3
Sum	50	322	356	23	11	34	30	46	1000	33	328	324	35	16	48	61	35	1000

B. At 2,000 meters

	N	NE	E	SE	S	SW	W	NW	Sum	N	NE	E	SE	S	SW	W	NW	Sum
	January–February–March									April–May–June								
a	..	..	..	..	..	..	..	..	27	..	..	..	..	..	..	..	..	56
b	64	116	139	29	18	29	12	23	430	80	120	128	40	16	20	40	52	496
c	12	192	163	0	0	6	12	35	420	48	128	124	28	0	8	28	12	376
d	0	58	41	0	0	0	0	6	105	4	32	24	0	0	0	0	8	68
e	0	6	12	0	0	0	0	0	18	0	0	4	0	0	0	0	0	4
Sum	76	372	355	29	18	35	24	64	1000	132	280	280	68	16	28	68	72	1000
	July–August–September									October–November–December								
a	..	..	..	..	..	..	..	..	111	..	..	..	..	..	..	..	..	44
b	43	82	138	78	30	39	26	34	470	54	126	137	65	14	36	22	47	501
c	17	125	121	17	0	13	17	22	332	14	115	162	18	11	14	25	28	387
d	9	26	30	0	0	0	9	9	83	0	25	25	0	0	0	14	0	64
e	0	4	0	0	0	0	0	0	4	0	4	0	0	0	0	0	0	4
Sum	69	237	289	95	30	52	52	65	1000	68	270	324	83	25	50	61	75	1000

C. At 3,000 meters

	N	NE	E	SE	S	SW	W	NW	Sum	N	NE	E	SE	S	SW	W	NW	Sum
	January–February–March									April–May–June								
a	..	..	..	..	..	..	..	..	59	..	..	..	..	..	..	..	..	85
b	15	176	192	66	51	22	15	30	567	78	83	110	55	41	37	32	83	519
c	0	154	147	7	0	0	7	22	337	32	74	55	32	5	28	50	46	322
d	0	22	15	0	0	0	0	0	37	5	23	18	9	0	0	0	14	69
e	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	5
Sum	15	352	354	73	51	22	22	52	1000	115	185	183	96	46	65	82	143	1000
	July–August–September									October–November–December								
a	..	..	..	..	..	..	..	..	61	..	..	..	..	..	..	..	..	68
b	49	121	82	77	44	44	33	16	466	45	103	152	71	40	67	17	62	557
c	11	82	127	60	27	38	22	38	405	26	107	103	36	0	26	17	22	337
d	0	11	6	11	0	11	6	11	56	0	17	4	4	0	4	0	9	38
e	0	6	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0
Sum	60	220	215	148	71	93	61	71	1000	71	227	259	111	40	97	34	93	1000

TABLE 2—*Continued*

D. At 4,000 meters

	N	NE	E	SE	S	SW	W	NW	Sum	N	NE	E	SE	S	SW	W	NW	Sum
	January–February–March									April–May–June								
a	..	..	..	..	..	..	..	..	73	..	..	..	..	..	..	..	..	94
b	45	108	135	72	45	9	18	45	477	54	90	84	48	72	48	90	36	522
c	0	90	153	72	9	9	9	9	351	0	48	72	48	6	48	78	36	336
d	0	18	45	18	0	0	0	0	81	0	0	0	6	0	6	24	12	48
e	9	9	0	0	0	0	0	0	18	0	0	0	0	0	0	0	0	0
Sum	54	225	333	162	54	18	27	54	1000	54	138	156	102	78	102	192	84	1000
	July–August–September									October–November–December								
a	..	..	..	..	..	..	..	..	79	..	..	..	..	..	..	..	..	47
b	57	70	76	57	57	64	64	76	521	57	104	83	104	52	26	52	57	535
c	25	76	70	19	13	25	51	45	324	15	78	98	26	36	31	47	31	362
d	13	6	13	6	0	13	25	0	76	0	21	10	0	0	5	0	10	46
e	0	0	0	0	0	0	0	0	0	0	10	0	0	0	0	0	0	10
Sum	95	152	159	82	70	102	140	121	1000	72	213	191	130	88	62	99	98	1000

E. At 5,000 meters

	N	NE	E	SE	S	SW	W	NW	Sum	N	NE	E	SE	S	SW	W	NW	Sum
	January–February–March									April–May–June								
a	..	..	..	..	..	..	..	..	130	..	..	..	..	..	..	..	..	26
b	40	70	140	90	50	20	40	30	480	39	26	59	39	65	91	46	52	417
c	10	80	150	30	10	20	10	10	320	13	72	13	52	46	118	72	52	438
d	0	20	40	10	0	0	0	0	70	7	13	7	0	0	20	52	13	112
e	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	0	7
Sum	50	170	330	130	60	40	50	40	1000	59	111	79	91	111	229	177	117	1000
	July–August–September									October–November–December								
a	..	..	..	..	..	..	..	..	27	..	..	..	..	..	..	..	..	31
b	72	29	72	80	44	44	72	58	471	50	69	50	81	19	50	75	94	488
c	29	44	51	44	21	51	66	95	401	44	50	56	31	25	62	82	62	412
d	7	15	7	15	7	21	15	7	94	0	6	0	0	0	19	19	19	63
e	0	0	0	0	0	0	0	7	7	0	0	0	0	0	0	6	0	6
Sum	108	88	130	139	72	116	153	167	1000	94	125	106	112	44	131	182	175	1000

F. At 6,000 meters

	N	NE	E	SE	S	SW	W	NW	Sum	N	NE	E	SE	S	SW	W	NW	Sum
	January–February–March									April–May–June								
a	..	..	..	..	..	..	..	..	6	..	..	..	..	..	..	..	..	53
b	14	101	58	101	43	29	43	15	404	45	22	15	74	52	67	52	67	394
c	14	144	173	72	15	14	0	15	447	22	30	30	15	44	118	81	52	392
d	0	15	71	43	0	0	14	0	143	7	7	0	15	7	44	37	15	132
e	0	0	0	0	0	0	0	0	0	0	0	0	0	0	22	15	0	37
Sum	28	260	302	216	58	43	57	30	1000	74	59	45	104	103	236	192	134	1000
	July–August–September									October–November–December								
a	..	..	..	..	..	..	..	..	50	..	..	..	..	..	..	..	..	16
b	34	17	43	17	43	77	94	60	385	15	89	30	59	0	81	81	59	414
c	26	51	51	26	34	77	111	43	419	44	45	44	30	37	81	67	67	415
d	0	26	17	0	0	17	51	26	137	0	7	15	0	0	22	44	30	118
e	0	0	0	0	0	0	0	9	9	0	0	0	0	0	22	15	0	37
Sum	60	94	111	43	77	171	256	148	1000	59	141	89	89	37	206	217	156	1000

TABLE 2—*Concluded*

G. At 8,000 meters

	N	NE	E	SE	S	SW	W	NW	Sum	N	NE	E	SE	S	SW	W	NW	Sum
	January–February–March									April–May–June								
a	..	..	..	..	..	..	..	..	0	..	..	..	..	..	..	..	..	0
b	0	23	23	46	46	0	46	46	230	0	0	20	0	10	50	10	10	100
c	23	46	210	117	23	46	23	71	559	10	10	30	30	30	140	120	60	430
d	0	0	71	94	0	0	46	0	211	0	0	10	0	40	120	80	130	380
e	0	0	0	0	0	0	0	0	0	0	0	0	0	0	40	10	40	90
Sum	23	69	304	257	49	46	115	117	1000	10	10	60	30	80	350	220	240	1000
	July–August–September									October–November–December								
a	..	..	..	..	..	..	..	..	0	..	..	..	..	..	..	..	..	0
b	11	0	0	0	34	23	34	23	125	11	0	11	0	32	21	11	32	118
c	23	56	34	34	56	117	170	44	634	21	63	32	32	32	95	150	42	467
d	12	0	12	12	12	56	101	45	250	0	21	32	0	11	117	85	96	362
e	0	0	0	0	0	23	68	0	91	0	0	0	0	0	21	21	11	53
Sum	46	56	46	46	102	219	373	113	1000	32	64	75	32	75	254	267	181	1000

H. At 10,000 meters

	N	NE	E	SE	S	SW	W	NW	Sum	N	NE	E	SE	S	SW	W	NW	Sum
	January–February–March									April–May–June								
a	..	..	..	..	..	..	..	..	0	..	..	..	..	..	..	..	..	0
b	0	0	0	0	41	0	0	0	41	0	0	0	17	17	0	34	0	68
c	0	42	83	42	42	125	167	83	584	34	0	17	34	0	86	34	52	257
d	0	83	42	41	42	83	42	0	333	0	0	0	34	0	225	139	86	484
e	0	0	42	0	0	0	0	0	42	0	0	0	0	0	122	69	0	191
Sum	0	125	167	83	125	208	209	83	1000	34	0	17	85	17	433	276	138	1000
	July–August–September									October–November–December								
a	..	..	..	..	..	..	..	..	0	..	..	..	..	..	..	..	..	0
b	0	17	0	0	0	0	0	17	34	0	16	16	16	0	16	0	0	64
c	0	0	17	0	33	216	83	67	416	0	16	49	0	0	49	65	132	311
d	0	0	17	0	33	100	216	67	433	16	16	17	17	49	82	132	82	411
e	0	0	0	0	0	33	67	17	117	0	16	0	0	0	49	116	33	214
Sum	0	17	34	0	66	349	366	168	1000	16	64	82	33	49	296	313	247	1000

Coördinates of the pilot balloon station: Lat., 17° 32′ S; Long., 149° 34′ W; elevation, 92 meters.

lar variations in velocity: this remark is equally true of the winds from the sector south to northwest.

2. These last-named winds are weak in the lower layers of the atmosphere, up to 1500 meters (land and sea breezes); but aloft they rapidly attain the highest velocities observed: at 8000 meters they already represent 95 per cent, on the average, of winds exceeding 50 and 75 km. per hour.

3. The winds of the sector northeast to east, surface winds, are normally moderate or fairly strong, with velocities most often less than 50 or even 25 km. per hour.

4. Finally, there is a rather marked annual variation.

Annual Variation of the Free-Air Winds

Our data make possible the following generalizations concerning the annual fluctuations in velocity and direction of the free-air winds, and their limits in the vertical:

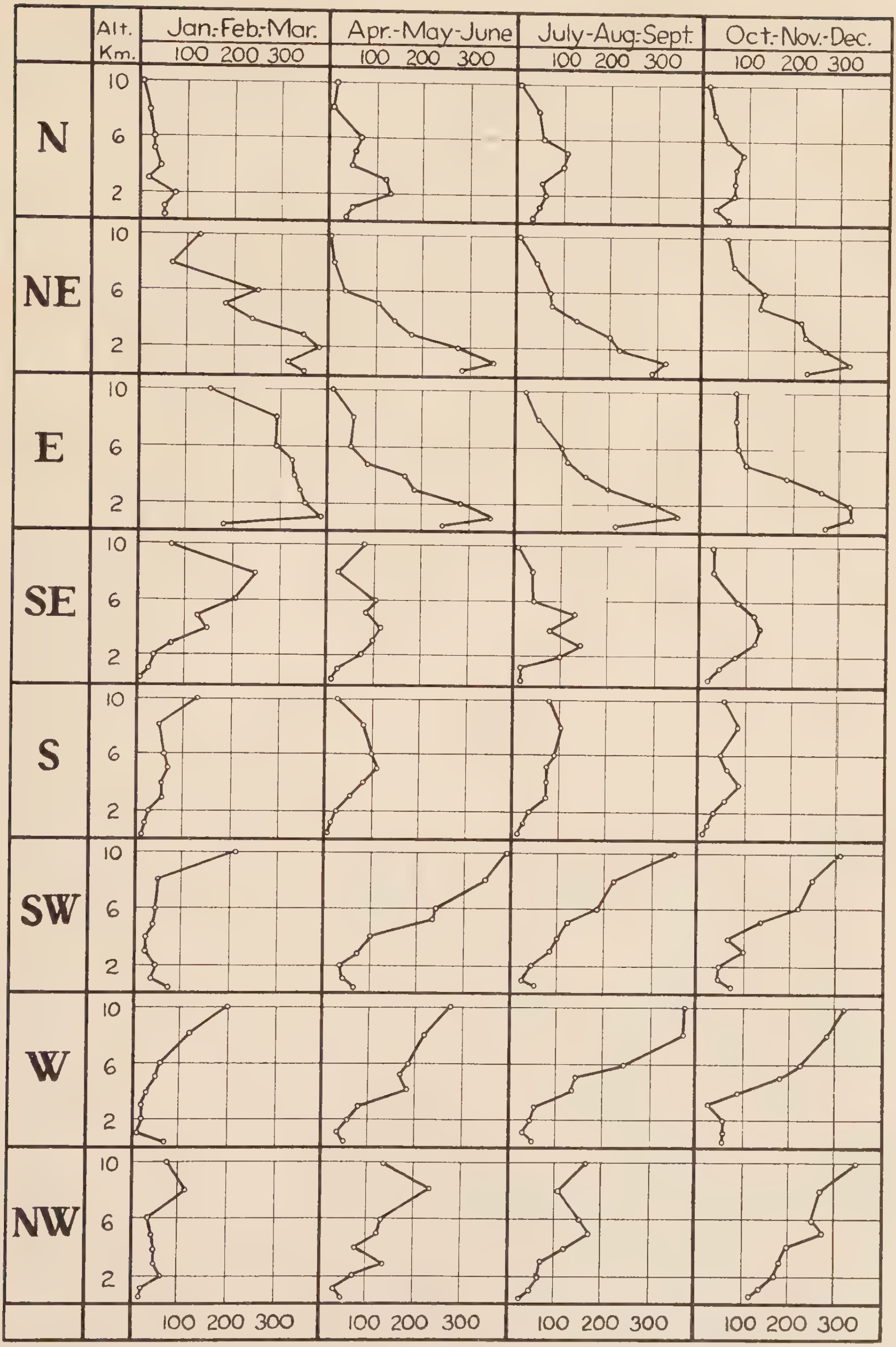

Fig. 2. Mean frequencies of directions of free-air winds at Papeete, Tahiti, 1934–1938. Frequencies are plotted on the axes of abscissas as proportional parts of 1000.

1. *Velocity.* The annual variation is not marked, undoubtedly because of the inaccuracy of measurements. It should, however, be noted that great departures from mean velocity are more frequent in the warm than in the cool season. This fact is directly connected, it would seem, with the passage of more numerous depressions at this time, from November to April. No precise rule can be derived from the observations.

2. *Direction.* The trade wind, definitely a NNE to NE wind in January, February, and March, turns to NE to E in May–June, to ENE to ESE in August–September, and then returns to NE in November–December. (In May to August, and sometimes in September, a slight increase in frequency of winds from SE is observed.) The annual variation of the antitrade is also clear: SSW to WSW in January–February–March, it blows from SW to W in May–June, turns distinctly to W in August–September, and swings rather sharply toward NW in October–November, to return finally to W and SW in December. (From April on, more numerous winds from NW are recorded.

3. *Vertical limits.* The two limits in the vertical that we have earlier designated z_1 and z_2, the upper boundary of the trade wind and the base of the antitrade respectively, are subject to a double oscillation of great amplitude, such that from May to October z_1 is regularly encountered between 1500 and 3000 meters above sea level, and z_2 1000 to 2500 meters higher; while from October to March z_1 is usually pushed upward beyond 6000 meters: the thickness of the layer z_1–z_2 decreases, and tends at times to disappear. It is not rare, to this time, to see z_1 rise sharply to and even beyond 10,000 meters; but the reverse change may occur with comparable rapidity. The characteristic quality of the rainy season resides therefore particularly in abrupt oscillations in height of the limits of the currents, coinciding with unforeseen fluctuations in velocity; *the limits z_1 and z_2 are, however, certainly higher, on the average, than during the corresponding cool (dry) season.*

FREE-AIR WINDS AND ATMOSPHERIC PRESSURE

Our intention has been to present in this note no more than a résumé of the results that appear to follow from a first examination of the data we possess on the relations between irregular or periodic changes in weather and the fluctuations of the free-air winds. A general study of this question will be made later. In the present state of our knowledge, it appears that the following statements may be justified:

1. Irregular increases in pressure coincide with increased activity of the trade wind; it is further noted that the trade wind is regular and strong during periods of fair weather.
2. The limit z_1 is subject to abrupt fluctuations during the passage of depressions; at these times the layer z_1–z_2 tends to disappear.
3. Occasional low pressures are apparently connected with a strengthening and lowering, both usually rapid, of the antitrade.
4. A change in weather is often accompanied by a reversal of the sense in which the free-air winds turn with increasing elevation.
5. In the course of the year the average high pressures of the cool (dry) season coincide with a seasonal lowering of the antitrade; but on the contrary the increase in height of the trade wind and its annual periodic strengthening are associated with the average low pressures of the rainy season.

Figure 3 shows the mean values of atmospheric pressure at the height of the station for each direction of the wind at 2000 and 4000 meters. It seems to follow from these values that, for the same period, winds from SW, W, and NW correspond in general to pressures much lower than those observed with winds from N, NE, E, and SE at the same elevations.

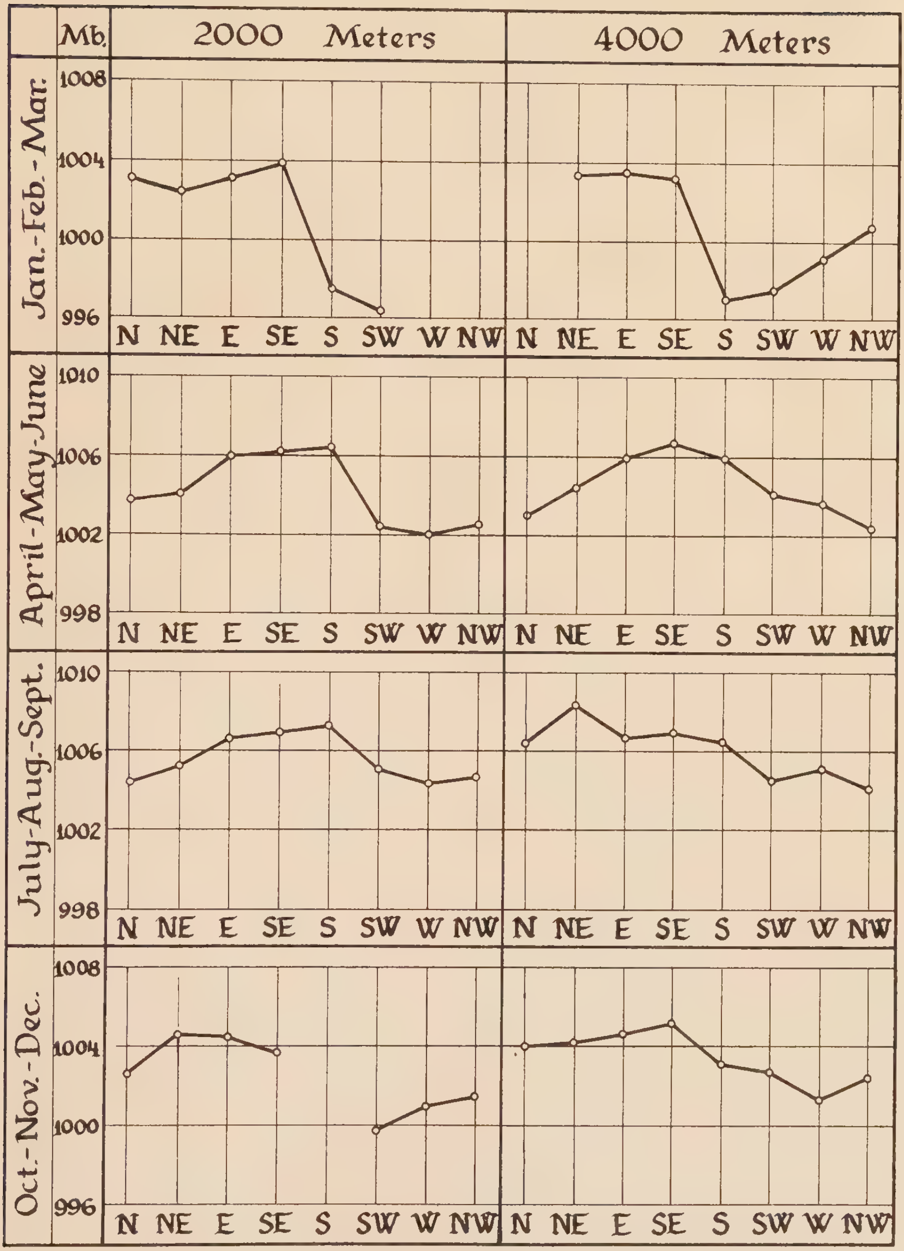

Fig. 3. Mean pressure associated with winds from different directions at 2 km. and 4 km. elevation, Papeete, Tahiti, 1938.

PRECIPITATION RECORDS IN CALIFORNIA TREE RINGS

By Edmund Schulman

Introduction

The varying width, in successive years, of the annual rings of ponderosa pine and other trees has been found by Douglass[1] to record closely the varying seasonal rainfall in Arizona and elsewhere. In order to eliminate numerous environmental and other nonclimatic factors to which trees are subject, it is necessary to use special criteria of selection and methods of reduction of specimens. The essential basis of the analysis lies in a close consideration of the support given to the record from any one tree by the records in other trees in the same climatic region. This is the cross-dating principle, which makes possible the elimination from the data of much of what is, from the point of view of climatic record, the "random" term in radial tree growth.

Cross dating not only permits the correct identification of the year of growth of any given ring, but also allows some study of the distribution of precipitation throughout the year and of local differences in annual precipitation. The sensitivity of the ring sequence, that is, the degree of fluctuation in ring thickness from year to year, is in combination with its cross-dating quality the factor which assures us that what we read in the ring record is of climatic significance.

It cannot be overemphasized that the cross-dating principle and the multitude of considerations it gives rise to lends to tree-ring analysis a precision that is absolutely necessary if the results from a climatological viewpoint are to have permanent value. Tree-ring studies in which cross identity is treated as a casual character have almost invariably led to faulty conclusions. The principle is simple in concept, but in its application demands considerable practical experience.

The present report consists essentially of two parts: (1) a detailed study of the Monterey pine in relation to rainfall, and (2) some general notes on cross dating in the conifers of California and the climatic history contained in the records of these trees.

Monterey Pines

The Monterey pine (*P. radiata*) is of special interest because (1) it has received a good deal of attention from botanists, and (2) interpretation of its ring sequence is made complex by a type of false annual ring which is rare in pine. Previous investigation[2] with respect to the climatic indicator value of Monterey pine has led to the conclusion that it is completely unreliable so far as its ring record is concerned. Studies of the unformity of record in one tree, by dissection, indicated that the sequence of ring widths from any one level or radius of the trunk was likely to be quite different from that of another radius. Under such conditions cross dating would be impossible, and of course no climatic record could be obtained. While it was emphasized that the dissected-tree studies were preliminary in character and on limited material, so that further confirmation was desirable, this work on Monterey pine was apparently complete enough to discourage further studies.

However, it must be remembered that these results were obtained by considering, in the manner of classical botany, the response of the tree as an individual. They logically followed from that approach; yet there are differences in interpretation which may be very great when the special requirements of the tree-ring analyst are met. The two most important of these requirements underlying gross climatologic relationships in tree rings—selection and cross dating—have been mentioned in the first paragraph of this report.

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[1] A. E. Douglass, "Climatic Cycles and Tree Growth," *Carnegie Inst. Wash. Publ.* 289, Vol. 1–1919, Vol. 2–1928, Vol. 3–1936.

[2] D. T. MacDougal and F. Shreve, "Growth in Trees and Massive Organs of Plants," *Carnegie Inst. Wash. Publ.* 350, Washington, 1924; D. T. MacDougal, "Studies in Tree Growth by the Dendrographic Method," *Carnegie Inst. Wash. Publ.* 462, Washington, 1936.

First, as to selection. The dissection studies noted above were on a tree which came from a site exposed to winds from the ocean.[3] The effect of winds in introducing irregularities in growth about the stem is well known; on exposed slopes this effect is much less, of course, than on windswept ridges where the trees are characteristically gnarled and dwarfed, but the effect is still important enough to make it desirable, for the purposes of climatic history, to select trees protected from wind. The other criteria of selection, such as a desired minimal in special influences of soil-moisture conservation properties of the site, environment, and the like, are of course also very important. It is thus *a priori* probable that dissected tree tests on specimens of Monterey pine, chosen for their ability to record climatic history, would greatly reduce the force of the conclusion that "it is seldom that a ring is continuously greater or less than an adjacent ring when they are followed for several meters up the trunk."[4] Indeed, it will appear from the studies below that it is necessary to insert a "not" before the word "continuously."

Second, consider the cross-dating principle as applied to these results. It was found that some rings had a width relative to their neighbors which in greater or less degree was not proportional to the rainfall of that year and thus led to the conclusion that the ring record was not reliable. Undoubtedly, this ring variability is present with varying importance in all trees; it is not possible to find a tree in which the "random" term in radial growth is completely absent. But experience in the Southwest has shown that averaging together the records from a group of five or more concurrent specimens from the same climatic region serves to eliminate or greatly reduce the random errors of this sort, so that the underlying climatic chronology emerges.

With the preceding considerations in mind, extensive collections of Monterey pines were made on trips to the Monterey Peninsula in December, 1936, and March, 1937. Sites as diverse and separated as possible were selected. The sampled area represented roughly a triangle measuring five miles on a side. The valley bottoms were avoided as collection sites; usually, wind-protected slopes were chosen.

The reduction of these specimens involved only one new problem, the correct identification of false annual rings of a new type. Ordinarily, false annual rings are easily recognized by their hazy outside boundary. Since they usually result from some interruption in the growing season, they are characterized by a band of radially compressed, dark-colored, and thick latewood cells, which gradually gives way to the more open light-colored cells of spring wood type. But MacDougal has already pointed out an occurrence[5] in the Monterey pine of a false annual ring in 1918 which had a sharp outside boundary, so that it was indistinguishable from the ordinary true annual rings; dendrographic records showed that the tree had renewed its growth following an extraordinary rainfall of more than five inches in mid-September, ordinarily an almost completely rainless month. Additional examples came to light in the samples collected. It was possible, by recourse to other specimens, to recognize these as extreme types of false annual rings, for while these extra rings were annual-like in some trees or radii, in others they showed the characteristic hazy outside.

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[3] Shreve, 1924 (see note 2), p. 97.

[4] Shreve, 1924, p. 99.

[5] D. T. MacDougal, "Growth in Trees," *Carnegie Inst. Wash. Publ.* 307, 1921; MacDougal, *op. cit.*, p. 31.

While the significance of these differences in duration of activity of the cambium in different parts of the same tree and in different trees is of interest to plant physiologists, we are concerned primarily with the climatic relationships. We ask the question, Can we, from the existence of sharp extra rings in Monterey pine, draw any conclusions about the climate?

The rainfall at Monterey, as elsewhere on the California coast, begins usually in late autumn, reaches a maximum during the winter, and becomes very light by the end of spring. The summers are completely rainless, but fog is more prevalent than in the winter. Occasionally, rains fall in September or October. Under the oceanic influence the temperature range is very small and the winters are mild.

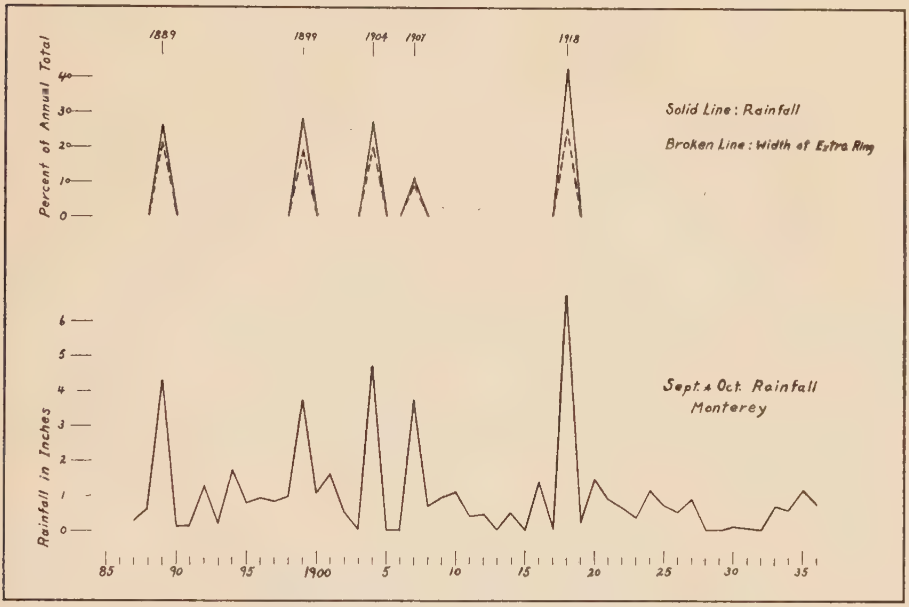

Fig. 1. The effect of excessive September–October rainfall in formation of sharply bounded extra rings in Monterey pine, based on 11 trees in three groups, near Carmel, California. Only the five years indicated above were represented by sharp extra rings in most of the specimens.

An autumn extra ring, as in 1918, was found to occur also in 1889, 1899, 1904, and 1907. In figure 1 (lower curve) is shown the rainfall for September plus October at Monterey; it is at once evident that the years when an extra ring was laid down in autumn were those of exceptionally heavy rains in September or October, and only those. It would seem that these rains sharply reawakened the cambium after the resting period induced by the summer drought; at the same time, the impulse generated by the rains could not carry the tree across the relatively long interval to the normal beginning of the next growing season, so that radial growth again came to a full stop in the meantime. Thus this type of extra ring represents an extension rather than an interruption of the normal growing season. Figure 1 also shows that with a large maximum in the September–October rain there is associated only a slightly greater fall ring than with a moderate maximum; the effect of a greater percentage of runoff in the former case is evident. Transitional types of false rings, some of them resulting from heavy November rains, were found to be numerous. Some details of their relation to climate have already been published.[6]

Very old specimens serve as a valuable control against false annual rings. It has long been established that very young trees, and fast-growing trees, have a much greater tendency to lay down multiple rings than do slow-growing, old trees. This is fully borne out by the Monterey pine. Normally, old trees reach a maximum age of 80 to 100 years. Two trees in our collection, growing under natural conditions in a protected side valley several miles inland from the ocean, yielded increment cores reaching back to 1827 and 1832. With allowance for a conservative number of rings from the inner end of the core to the pith of the tree, and for time needed by the tree to reach breast height, these trees are well over 125 years in age. They show no September–October rings for the five years noted. Indeed, no false annual rings of any type occur in these slow-growing specimens, except for the year 1861 in one tree and 1874 in the other. With no support from other specimens for the types of false ring to which these isolated instances belong, no statement about additional instances of strong September–October rains in these years may be made. It is evident that even the excessive September–October rains of the five years mentioned could not reawaken the cambium of these old trees to renewed activity so early in the fall. Other old trees from flat regions near the coast support these results. It is interesting to note that with the possible further exception of 1844 there are no sharp rings of the autumn type other than those indicated above, which are consistently present in our specimens. There is some indication of a frequency of such September–October rings early in the 19th century, to correspond with the unusual frequency near 1900, but not enough specimens of old trees are included in our collection to carry the record back with certainty.

With the solution of the identity of false rings we turn now to the climatic records in the annual growth as a whole. As a necessary preliminary to attempted correlations with climatic elements, we investigate the cross dating between the various groups of Monterey pine. For each collection site the records from a number of trees have been averaged into a mean group curve. The essential step in this process is the elimination from the record of each tree of the age curve, that is, the smoothed decrease in average ring size with increasing diameter of the tree, on which the year-to-year fluctuations depending on climate are superposed. This operation expresses each ring width not in absolute value, but in percentage of departure from a mean or standardizing line (see fig. 2, *b*, curve DM 51), and makes it possible to average into one curve records from trees of various ages.

Figure 2, *a*, displays the mean growth curves for all the groups. The evident similarity makes any one rather generally representative of all. The grand mean curve of 23 trees may thus be taken as very nearly the best climatic record that Monterey pines can offer.

The two curves of figure 2, *b*, show clearly that a serious new element entered into and distorted the ring record of these trees after 1880. Since irrigation was introduced after that time, following development of a resort hotel at the site, the relationship is clear. The smoothed curves since 1880 are strongly reminiscent of the damped year-to-year variations of the rings in sequoias growing in swampy basins, and pines on naturally well-watered sites. The striking differences in the general course of growth of these two trees after irrigation emphasizes also the danger in deductions about climatic cycles from climatologically poor material. These curves also suggest that with elimination of

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[6] E. Schulman, "Classification of False Annual Rings in Monterey Pine," *Tree-Ring Bulletin*, Vol. 4, No. 3, January, 1938; *Carnegie Inst. Wash. Yearbook*, 1937.

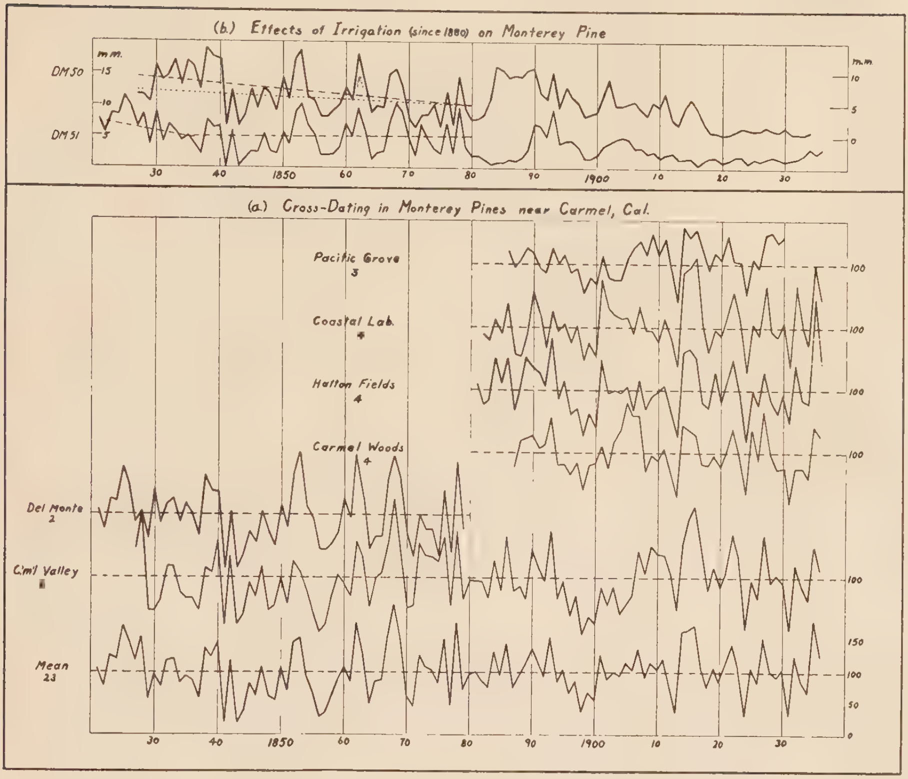

Fig. 2. *a*. Similarity in the growth curves of various groups of Monterey pine. *b*. Irrigated trees: to exclude the effect of irrigation, only those parts of the growth record of these trees which antedate 1880 enter into the grand mean curve for 23 trees. For DM 50 two alternative standardizing lines are indicated; comparison with that for DM 51 led to the upper one as the better estimate of growth trend.

water supply as a growth-conditioning factor, no other single element is dominant; thus variation in radial growth has apparently become a function mainly of the complex of factors peculiar to the individual tree.

The mean growth curve for Monterey pine rather faithfully represents the seasonal rainfall at Monterey, computed on the basis of a year beginning November 1 in order to agree with the assignment of the occasional September–October extra ring to the growth of that year. The correlation coefficient for 56 years is 0.77 ± 0.04, using all 23 trees; for the December, 1936, group alone, 11 trees, the coefficient is 0.70 ± 0.05 (see fig. 3).

The close correspondence between tree growth and rainfall exhibited in figure 3, *a*, still fails to reveal fully the remarkable dominance by rainfall of the growth of Monterey pine. Detailed examination of the two important differences between the curves of figure 3, *a*, shows (1) that the difference in trend for 1918 may be traced to the relatively excessive runoff during the five-inch mid-September rain—an effect which may also have been of importance in 1904, though apparently not in 1889; and (2) that the generally somewhat deficient growth of 1904–1911 appears to be another runoff effect. Referring to figure 2, we note that only the Carmel Woods group shows an absolute maximum of growth during this period of the greatest rainfall of record. Since this group

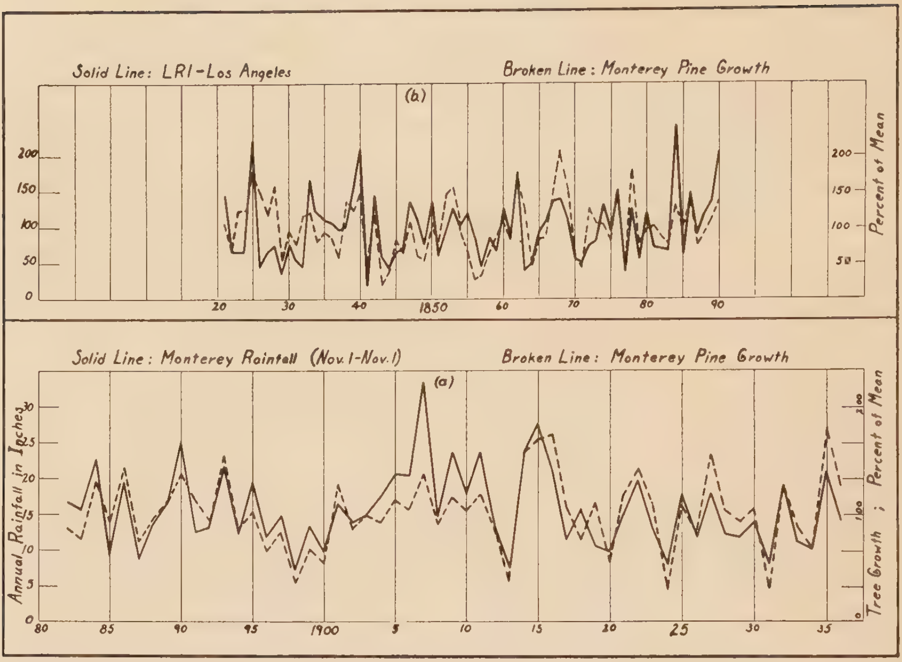

Fig. 3. *a.* The relation between seasonal precipitation and growth of Monterey pine, based on mean of six groups, 23 trees, near Carmel. *b.* Comparison of Monterey pine with Lynch's Rainfall Index for the Los Angeles Area. Only a few trees carry back the growth record to before 1885.

was the only one which came from well below the top of a slope, the summation effects of downhill seepage may have been important during this very wet interval. However, for the entire period 1887–1936 the correlation coefficient with rainfall of this four-tree group is 0.73 ± 0.04.

Since the seasonal rainfall shows essentially the same relative fluctuation from year to year for the entire coastal region of central and southern California, we examine next the relationship between the entire Monterey tree-growth curve and Lynch's Rainfall Index, compiled for the region 400 miles to the south. The two records are found to be in close agreement (fig. 3, *b*) ; the correlation coefficient for 110 years is 0.62 ± 0.03.

No simple direct relationship between temperature and tree growth could be found to apply to the curve as a whole.

No attempt was made to analyze the rather short Monterey growth curve for long cycles. Inspection indicates a short cycle of 2 years, which is well known in California rainfall. This is well shown by a curve of accumulated departures (fig. 4), obtained by applying a change of sign to every alternate increment (the difference in growth in successive years) and forming a cumulative sum. By its major changes of slope this curve indicates reversals in phase of the 2-year cycle. This "2-year reversal test" shows generally the features already obtained on Lynch's Index.[7] Of note in figure 4 are the changes which occur roughly every 23 years. We see that from 1826 to 1844 the 2-year cycle was fairly regular with a maximum in the even years. A disturbed interval from 1844 to 1870 indicates that this cycle faded out or became irregular

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[7] Douglass, 1936 (see note 1), p. 88.

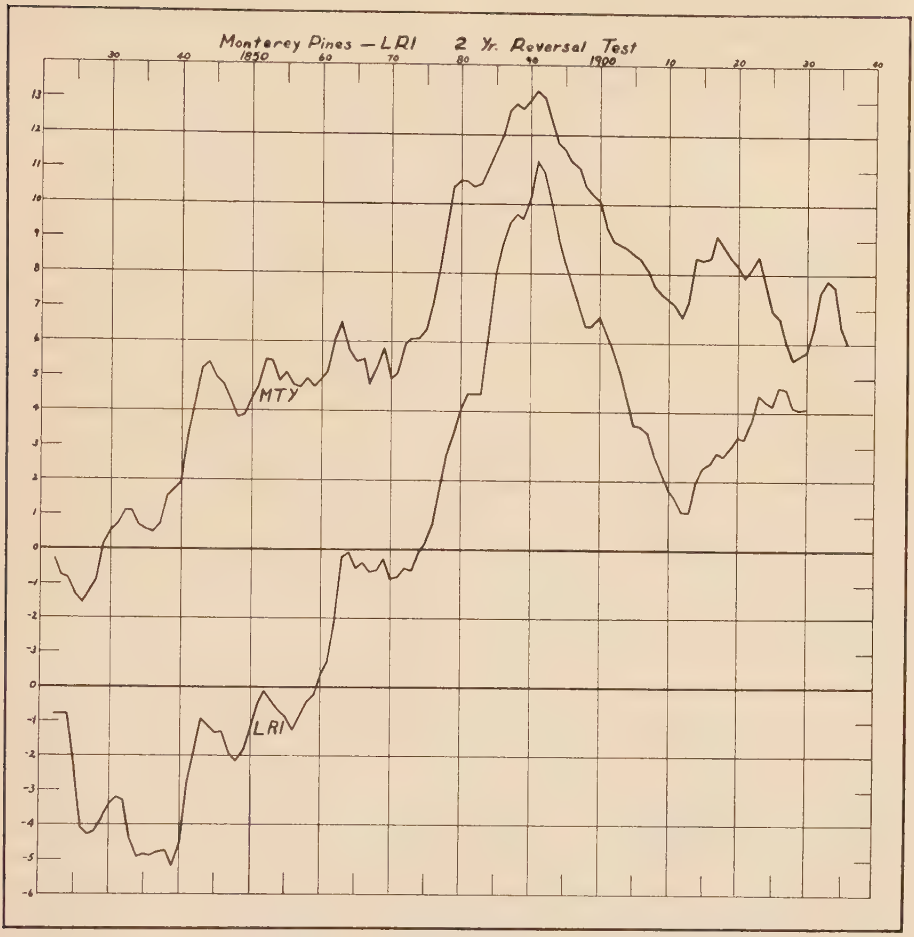

Fig. 4. Variations in the two-year cycle in tree growth at Monterey.

during this time; it became quite stable in 1870 and lasted to 1891. At 1891 an abrupt change of phase occurred, the maxima now falling on the odd-numbered years; after a very strong operation of this cycle, it became irregular again in 1912, and remained so for the rest of the data. The 23-year beat assumes importance because a 23-year cycle is very pronounced in California tree growth in recent centuries.

EASTERN CALIFORNIA GROUPS

Previous investigation has shown[8] that the ponderosa pines of the eastern slopes of the Sierra Nevada and the Cascades are good recorders of seasonal precipitation, especially for the extreme years. Douglass[9] records several groups from the southern Sierra and the southern coastal mountains which show excellent cross dating. At the same time, because of the great range in climatic, topographic, edaphic, and other factors, significant differences in

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[8] E. Antevs, "Rainfall and Tree Growth in the Great Basin," *Am. Geog. Soc. Special Publ.* 21; *Carnegie Inst. Wash. Publ.* 469, 1938.

[9] Douglass, 1928 (see note 1), pp. 86–90.

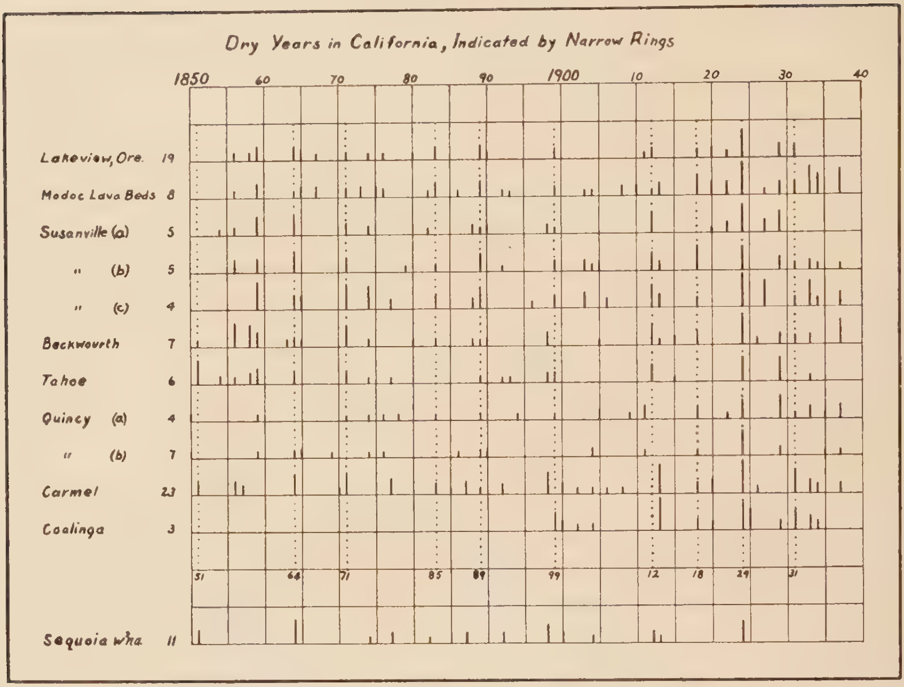

Fig. 5. Skeleton plots of twelve groups, 102 trees, in the California region, showing close agreement in drought-year effect on trees.

chronology (the annual sequence of thick, thin, and other ring characters) frequently appear in regions only a few miles apart. To throw more light on these local differences, a large number of groups of specimens were collected during June, 1939, principally in the Reno-Susanville-Modoc region of so-called Eastside Timber. Since the mountainous areas of this locality have soils largely of decomposing lava rocks, with the consequent high water-holding capacity, it was usually necessary to seek the steep slope and ridge sites in order to obtain the best climatic records that the trees could furnish.

While studies of this material are yet quite incomplete, some results of analysis of the outside century of data may be noted. Figure 5 is a preliminary view of the cross-dating qualities in the various groups, in terms of the thin rings. Only those rings have been entered in the diagram which are emphatically smaller than their neighbors; the ordinates are roughly in inverse proportion to the size of the thin rings, so that in 1924, for example, which is represented in most of the trees as a microscopic ring, the ordinates are generally a maximum.

In this figure, the Lakeview (Oregon) plot, taken from Antevs' published data,[10] represents the most northerly of the groups. The Modoc, Susvanville, Beckwourth, and Tahoe groups are successively farther south. It is evident that a marked similarity exists in the chronologies for the various regions. Indeed, it was possible to date in the field and with precision most of the specimens collected in this region, once the underlying chronology was memorized. The dotted vertical lines call attention to ten outstandingly consistent thin rings since 1850. Several other years could probably be included in this set.

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[10] Antevs, 1938 (see note 8), Pl. I.

The Susanville (*a*) group is also extracted from Antevs. Additional groups on very dry sites were collected to test local variability, and two are plotted. It is evident that (1) a general agreement of a high order is present in the three groups and (2) minor differences in chronology are numerous. This last has a strong bearing on interpretation of correlations of tree growth with rainfall. Attempts are frequently made to resolve in detail the differences between tree growth and rainfall as functions of various other climatic and nonclimatic forces. It seems worth while to emphasize here that (1) the perfect climatic tree record does not exist; (2) local differences in chronology may easily be related, in dry regions, to differences in precipitation which are local and can be surprisingly large; and (3) in climatological studies of tree-ring records the macroscopic, many-group point of view is desirable, to provide a general control on the undoubtedly valuable contribution a detailed or microscopic study makes possible.

Attention may be directed in figure 5 to the year 1851, represented in the more northerly groups by a quite normal ring. It is evident that drought conditions for this year extended south from Tahoe (e.g., the giant sequoias near General Grant National Park show it as quite dry), but it is giving way to normal conditions at Beckwourth only some 50 miles to the north. This thin ring is of special importance because it has been found to occur in trees over an airline distance of 750 miles, from the southern Sierra to Pikes Peak.[11] The 1851 ring is a good example of the areal variability which is especially striking for the dry years. With several hundred years of records available from tree rings, it should be possible to obtain important information about the fluctuating limits of the areas of great excess or deficit in precipitation in the California region.

The Quincy records are of interest in showing the emergence of a chronology in a region with average seasonal rainfall of 45 inches or more. Only outstanding drought years such as 1924 are represented by emphatically small rings, but enough of such type years may be found to make the determination of dates sure. However, it was necessary to go to ridge specimens for these groups. Some groups collected on lower slopes and basins, while not highly sensitive to year-by-year changes, show cross dating between the various trees in the group, but also show generally rather significant differences in the mean course of tree growth as compared with the ridge-top specimens; it is evident that effects of conservation of soil moisture and downhill seepage are adding complexity to the basin records.

The Carmel (Monterey pine) and Coalinga (Coulter pine) groups, while near the coast of California, show much the same chronology as is found in the eastside timber 500 miles to the north and east. An interesting variant is 1913, which takes the place of 1912 as the drier year in the coastal regions.

The agreement in chronology which different species show is of importance. In the Modoc Lava Beds region, insect damage has destroyed much of the yellow pine, and many sites are too dry to support this species normally. A number of western junipers were sampled. The records are readily dateable and thus of climatologic significance, although somewhat complacent (relatively small variation in ring width in successive years). The difficulties which false annual rings introduce in other species of juniper growing in Arizona and New Mexico appear to be at a minimum in the western juniper of California and Oregon.[12] Red fir from various sites are dateable but complacent;

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[11] A. E. Douglass, "Evidence of Climatic Effects in the Annual Rings of Trees," *Ecology,* I:24–32, January, 1920.

[12] L. T. Jessup, "Precipitation and Tree Growth in the Harney Basin, Oregon," *Geogr. Rev.,* 25:310–312, 1935.

white fir and Douglas fir have not been included in any extensive groups because of extreme complacency. The agreement of Monterey and Coulter pine with Western yellow pine has already been mentioned. Some sugar pine specimens were taken, but in general the record is inferior in sensitivity to that of the associated ponderosa, although showing about the same chronology.

It is probable that the general agreement in chronology of different species in California is related to the type of climate characterized by an emphatic summer drought.

This summer drought is undoubtedly also related to the extraordinary absence of false rings in the eastside timber areas. This is in striking contrast to the numerous false annual rings of southern Arizona and the region to the east as far as western Texas; these are undoubtedly a consequence at least in part of the additional and relatively heavy summer rainy season. The factors of slow-growing specimens (the average mature tree sampled in the eastside area was several hundred years old) and a soil permitting a carry-over between occasionally spotty spring rains are also important in keeping false rings out of the record. In the sandy, extremely well-drained soil of the coastal Monterey pines, false rings are frequent in the young, rapid-growing specimens, but are absent in the older trees growing in the less sandy soil back in the hills.

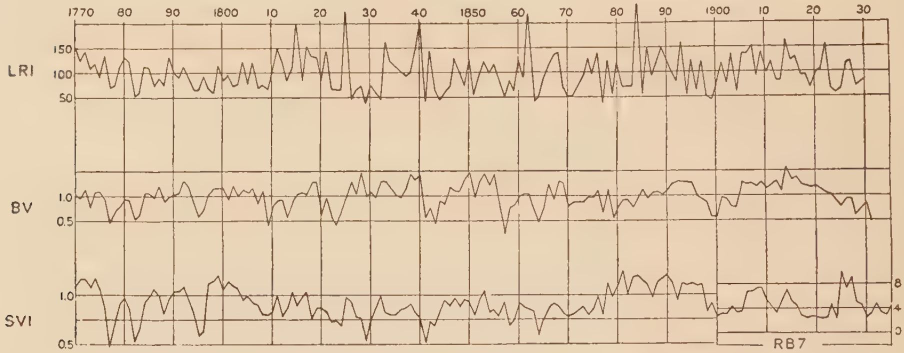

Fig. 6. Grant Park sequoia growth (SVI) and Bear Valley pines (BV), showing direct correspondence in many extreme years to Lynch's Rainfall Index (LRI) for the Los Angeles Area; a pine, RB-7, represents the sequoia region for the period 1900–1934. (From A. E. Douglass, *Climatic Cycles and Tree Growth,* Vol. III, 1936, p. 16.)

The general similarity in the tree-ring patterns over the great distances north–south in California emphasizes the importance to climatologists of the long sequoia record published by Douglass. This chronology, more than 3200 years in extent, is derived from the giant sequoias (*Sequoia washingtoniana*) growing on slopes and ridges rather than in the usually moist basins. A study of the sequoias on various sites showed that while rings in the basin trees fluctuated little in width in successive years and thus contained records not easily to be interpreted in terms of rainfall, the specimens growing on slopes showed a readable record and were evidently responding, at least in some degree, to precipitation changes from year to year.

Figure 6 shows the sequoia growth curve since 1770 and its relation to Lynch's Rainfall Index. The Bear Valley group of pines shown in the diagram is in location somewhat closer to the Los Angeles Area which LRI represents than to the region of the sequoias. While there is much difference in detail between the mountain record of SVI and the distant valley record of LRI, there is in evidence a strong similarity in fluctuation in the extremely dry or wet years, as well as a moderate general similarity in the curves.

SUMMARY

1. Two basic principles of precise tree-ring analysis are (1) the possible selection of trees so that some growth-limiting variable (e.g., water supply directly from precipitation in the temperate zone and desert regions) is more or less isolated in the ring record, all the other variable forces operating on the tree being at a minimum; and (2) good cross dating within a group of concurrent ring records from trees in the same local climatic area. Cross dating varies in quality as a direct function of average percentual change in ring width from year to year, and average deviation in relative width of any ring from the group mean for that year; thus good cross dating and a significant climatic record is present when easily recognized patterns of thick and thin rings can be found at various places in any ring sequence and in most or all specimens of the group.
2. Erroneous conclusions in previous investigation into the relationship of Monterey pines to seasonal rainfall arise in part because the preceding two principles were not sufficiently considered.
3. By cross dating, all false rings in Monterey pine can be correctly identified with respect to date.
4. False annual rings in Monterey pine are of two types: (1) with hazy outside boundary (the normal false ring in pine), and (2) with sharp annual-like outside boundary.
5. Sharp extra rings are traced to unusually heavy September or October rains, which occurred in 1889, 1899, 1904, 1907, and 1918.
6. The effect of 50 years of irrigation on two trees illustrates changes in the type of record, from a good rainfall-ring chronology to one in which the climatic response is submerged by the "random" term in radial tree growth.
7. Growth curves representing various groups of Monterey pine are extremely similar (high cross dating); the correlation coefficient of the mean curve with seasonal rainfall at Monterey is 0.77 ± 0.04.
8. The Monterey pine chronology provides a rainfall index extending back to 1821, and with poorer quality to 1787, which supplements the index, based on records of crop yields, floods, etc., compiled by H. B. Lynch.
9. A 2-year cycle with a change of phase or strength at approximately 23-year intervals is a pronounced feature in the last 115 years of Monterey pine growth.
10. Tree-ring groups from widely scattered sites in northeastern California show essentially the same chronology, with about 10 outstandingly thin rings in the last century consistently present in all groups.
11. A network of selected tree-ring groups makes available data throughout several centuries on the fluctuating limits of the areas of great excess or deficit in precipitation in the California region.
12. Various species, such as ponderosa and Jeffrey pine, sugar pine, western juniper, Monterey pine, and Coulter pine, show a substantial general agreement in chronology which is believed to be related to the pronounced summer drought in California.
13. The agreement of the sequoia chronology of Douglass with the recently collected groups, especially in drought years, emphasizes again the importance to climatologists of this 3200-year sequence.

CLIMATOLOGIE DE LA NOUVELLE-CALEDONIE

Par P. SURAUD et H. SCHMIDT

LES SERVICES météorologiques en Nouvelle-Calédonie ont été créés par décret du 11 Décembre 1938 et le personnel technique n'est arrivé à Nouméa que le 17 Mars 1939.

Avant cette date, des observations ont été effectuées par des observateurs bénévoles, mais ce n'est qu'à partir de Janvier 1935 qu'une documentation complète et sans lacunes a pu être réunie par les soins de M. H. Schmidt, professeur au Collège La Pérouse, à Nouméa. L'étude climatologique, exception faite des statistiques pluviométriques, ne repose donc que sur 4 années d'observations ; il serait donc prétentieux de vouloir entirer des conclusions définitives.

Cependant, pour marquer l'intérêt que porte la Nouvelle-Calédonie aux travaux du VI^e Congrès scientifique du Pacifique, le Service météorologique se permet de présenter ce travail sommaire pour lequel il sollicite la plus grande indulgence. Il s'excuse de sa maigre contribution et espère pouvoir présenter à un prochain Congrès une étude plus complète et plus concluante parce que basée sur un plus grand nombre d'années d'observation.

LA TEMPÉRATURE

Des mesures de température ont été effectuées à Nouméa (altitude 4m50 environ) à partir du ler Janvier 1935. Le tableau I donne :

1) les moyennes mensuelles et annuelle en degrés centigrades et centièmes. Ces moyennes sont calculées en prenant la moyennes des demi-sommes des extrêmes journaliers

$$\frac{m+M}{2}$$

2) l'anomalie moyenne.

3) les moyennes mensuelles et annuelles extrêmes.

4) les moyennes mensuelles et annuelle des amplitudes diurnes apériodiques.

5) les moyennes des extrêmes mensuels et annuels.

6) les extrêmes absolus de 1935 à 1938.

7) enfin, une moyenne de 17 ans calculée pour l'ensemble de la colonie par le Docteur Mialaret en prenant les moyennes de différents postes de la colonie de 1903 à 1919.

Ne figurent pas sur le tableau, les moyennes des températures aux 3 heures synoptiques; ces quantités ne figurant pas aux archives des 4 années d'observation.

On peut se demander avec quelle approximation sont données les valeurs moyennes.

D'après la formule de Feschner, c'est la moyenne d'Avril pour laquelle l'erreur probable est la plus forte, elle est égale à :

$$Ep = \frac{1.1955}{\sqrt{2n-1}} C = \frac{1.1955}{\sqrt{7}} 0{,}63 = 0°{,}28.$$

Sur la moyenne annuelle l'erreur probable est :

$$Ep = \frac{1.1955}{\sqrt{7}} 0{,}21 = 0°{,}094.$$

D'après ce calcul 4 années d'observations suffiraient à donner une valeur approchée de la moyenne annuelle à 0°,1 près. Pour obtenir une telle approximation pour toutes les moyennes mensuelles, il faudrait $(2,8)^2 \times 4$ soit 32 ans d'observation. Il resterait à prouver que l'anomalie moyenne calculée sur 4 années seulement donne une valeur suffisamment exacte pour que la formule de Feschner soit applicable. Ce pourrait être l'objet d'une étude ultérieure. De ces statistiques nous pouvons tirer les conclusions suivantes.

Grâce à sa situation géographique au voisinage du Tropique la Nouvelle-Calédonie possède une température moyenne élevée : 23°,53 de moyenne annuelle à Nouméa. On peut distinguer une saison chaude de Décembre à Avril au cours de laquelle le maximum atteint fréquemment 32 à 34° ; les mois froids sont Juin, Juillet, Août, Septembre pendant lesquels les nuits sont fraîches. Le minimum peut s'abaisser aux environs de 12°. Les températures extrêmes de 1935 à 1938 sont 12°,2 en Juillet et Septembre et 35°,5 en Février.

Mais, grâce à sa situation océanique, les saisons sont peu marquées et la variation annuelle faible. L'écart entre les moyennes mensuelles extrêmes n'est que de 6°,91 ; 26°,91 en Février, 20°,00 en Juillet.

Pour les mêmes raisons l'amplitude de la variation diurne est faible : 7°,21 de moyenne annuelle. Elle varie d'ailleurs peu avec la saison : 6°,01 en Avril, 8°,12 en Septembre. Toutes ces statistiques se rapportent à Nouméa. Sur les autres régions de la Nouvelle-Calédonie nous ne possédons que des renseignements imprécis. D'observations isolées il semble que l'on puisse cependant tirer les conclusions suivantes. Il n'y a pas de différence marquée au point de vue de la température entre la côte Est et la Côte Ouest.

Les deux régions qui semblent les plus chaudes sont les environs de Nouméa et la région de Pouébo au Nord-Est de l'île.

La température moyenne doit décroître avec l'altitude, mais on ne possède aucune indication sur sa valeur à l'intérieur de la chaine montagneuse.

Le minimum absolu enregistré en Nouvelle-Calédonie est de 2°,7 le 22 Juillet 1937 à La Foa à 12 Km environ de la mer, par le Docteur Drayton. On a également enregistré 3°,5 à Païta le 20 Juillet 1905 et le 28 Juin 1906, 3°,6 le 8 Juillet 1912 à Dumbéa. Ces températures qui semblent anormalement basses ont été cependant certifiées exactes par des personnes dignes de foi.

LES PRECIPITATIONS

Les premières mesures pluviométriques ont été effectuées en Nouvelle-Calédonie dès 1903. En un certain nombre de postes, elles ont été depuis continuées avec une certaine régularité, de sorte que les statistiques correspondantes sont basées sur un nombre d'années d'observation relativement élevé (19 ans au minimum). Nous avons donné dans les tableaux se rapportant aux diverses stations étudiées en détail les indications suivantes :

1) Moyennes mensuelles et annuelles des hauteurs d'eau exprimées en millimètres et dixièmes (avec pour chaque station le nombre d'années d'observation et leur date) ;

2) Le facteur pluviométrique : hauteur mensuelle des précipitations, la hauteur annuelle étant supposée égale à 1000 ;

3) Le pourcentage uniforme : facteur pluviométrique théorique, la hauteur annuelle étant supposée également répartie sur tous les jours de l'année ;

4) Le quotient pluviométrique : quotient du facteur pluviométrique par le pourcentage uniforme ;

5) L'excès pluviométrique : différence algébrique entre le facteur pluviométrique et le pourcentage uniforme ;

6) Enfin, toutes les fois que cela a été possible, ont été données les valeurs extrêmes des hauteurs mensuelles et annuelles pour l'intervalle de temps indiqué dans le tableau afin de montrer la très grande valeur de la variabilité mensuelle et annuelle.

Suivent 2 tableaux se rapportant à Nouméa et aux 4 années de 1935 à 1938.

Le tableau V donne : le nombre moyen de jours de pluie pour chaque mois et par an en jours et dixièmes ; la probabilité des précipitations pour chaque mois ou par an : quotient du nombre moyen des jours de pluie par le nombre des jours du mois (ou de l'année), enfin le pourcentage, par rapport au nombre total de jours de précipitation, du nombre de jours où les hauteurs d'eau recueillies ont été comprises entre certaines limites 0^{mm},1 à ^{mm},9 ; 1^{mm} à 4^{mm},9 ; 5^{mm} à 9^{mm},9, etc. . . .

Suivant la convention généralement admise, on nomme jour de pluie ou de précipitation tout jour où une hauteur d'eau supérieure à 0^{mm},1 a été recueillie au pluviomètre, cette eau ne provenant pas d'une condensation : brouillard ou rosée et quelle que soit la nature de la précipitation : pluie, bruine, averse, grêle, etc.

Le tableau VI destiné à mettre en évidence les pluies de forte intensité donne pour chaque mois et pour l'année le pourcentage des hauteurs recueillies provenant de précipitations d'intensité donnée par rapport à la hauteur totale. Enfin une carte pluviométrique de la Nouvelle-Calédonie donne la répartition géographique des hauteurs de pluie.

A ce point de vue la Nouvelle-Calédonie peut se diviser en 3 régions bien distinctes :

1) Côte S-E de la région de Plum à la région de Yaté. C'est la partie la plus arrosée. A Yaté, la moyenne annuelle atteint 3^{m},38, à Plum 2^{m},40 environ ; à Prony 2^{m},30 environ.

2) La Côte Ouest, de Nouméa à l'extrêmité NW de l'île est au contraire faiblement arrosée. Les plus petites hauteurs d'eau sont recueillies dans les îles de la baie de Saint-Vincent : 0^{m},85 environ à l'Ile Parceval ; à Ouaménie 0^{m},88 ; à Tembia 0^{m},80 ; à Voh 0^{m},87.

On y trouve également les moyennes suivantes : Nouméa 1^{m},06 ; La Foa 1^{m},16 ; Gomen 1^{m},16 ; Koné 1^{m},14 ; Païta 1^{m},26 ; Bourail 1^{m},35 ; Vao (Ile des Pins) 1^{m},34 ; Ouitchambo 1^{m},36.

3) Enfin la Côte Est des environs de Thio à l'extrêmité Nord reçoit des hauteurs moyennes variant entre 2^{m} et 2^{m},60. Canala reçoit 2^{m},03 ; Ponérihouen 2^{m},54 ; Oubatche 2^{m},60 environ ; Hienghène 2^{m},50 ; Houailou 2^{m},02 ; Pouébo 2^{m},53.

Sur les hauteurs d'eau reçues par la chaine montagneuse nous n'avons aucune indication précise. Quelques observations anciennes et présentant de nombreuses lacunes ont été effectuées au Col d'Amieu (altitude 350^{m}). Il semble en résulter que la hauteur recueillie est légèrement supérieure à 2^{m} par an.

Comme dans un grand nombre d'îles où règne un vent dominant, il existe donc en Nouvelle-Calédonie une partie au vent et une partie sous le vent. Par suite de l'altitude de la chaine très souvent supérieure à 1000^{m} résultent les contrastes précités dans le régime pluvial.

La région S-E est exposée aux alizés du S-E et aux vents d'E. C'est la partie au vent ; elle est très arrosée.

Au contraire, la côte Ouest sous le vent, est relativement peu arrosée, car elle est protégée par l'écran montagneux sur lequel s'est effectuée la majeure partie des condensations.

La côte Est est exposée aux vents d'Est, mais son orientation de SE à NW qui est également celle de la direction générale de la chaîne, la rend parallèle aux alizés du SE de sorte que ceux-ci ne peuvent y amener que des précipitations peu abondantes. Cela explique le régime de transition entre les deux régimes extrêmes.

La carte pluviométrique annexée schématise cette répartition des précipi-

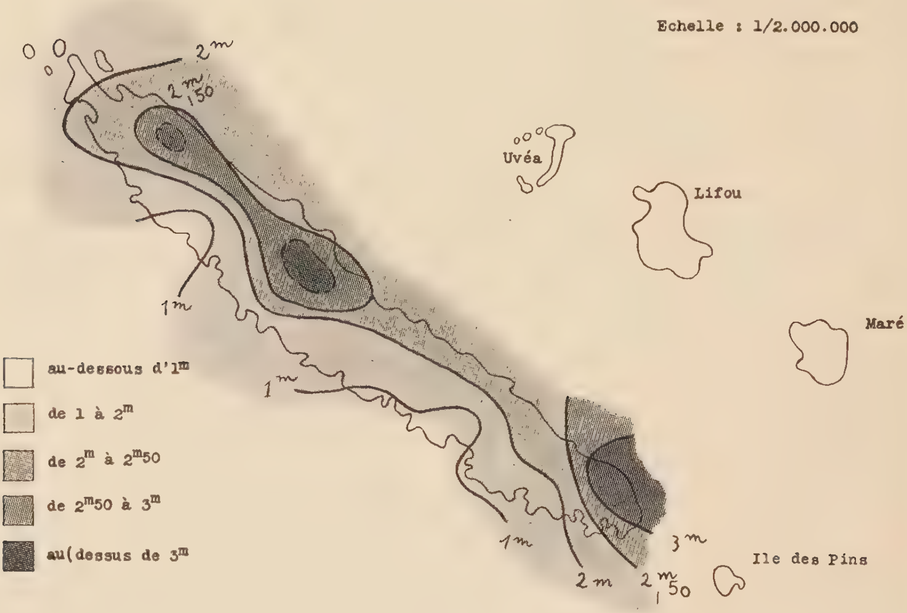

Fig. 1. Carte pluviométrique de la Nouvelle-Calédonie.

tations. Elle est cependant très hypothétique surtout dans la région Nord où les deux noyaux de pluie supérieurs à 3ᵐ sont tracés sans aucune observation, mais d'après la topographie de la région (Mont Panié, Mont Tchingu).

Une des caractéristiques du climat calédonien c'est l'extraordinaire variabilité des précipitations. Nous avons calculé pour Nouméa et pour Yaté les hauteurs extrêmes recueillies chaque mois et chaque année (intervalle de 19 ans à Yaté, de 15 ans à Nouméa).

Si on nomme variabilité pluviométrique le quotient de la différence des hauteurs extrêmes par la moyenne correspondante on a les résultats suivants :

	Janv.	Févr.	Mars	Avr.	Mai	Juin	Juil.	Août	Sept.	Oct.	Nov.	Déc.	An.
Nouméa....	1,26	1,40	2,45	2,21	2,14	1,56	2,39	1,40	3,78	3,19	8,08	2,22	0,98
Yaté......	2,32	1,30	1,59	2,38	2,69	2,76	2,21	2,66	3,46	2,57	7,18	2,46	0,83

Elle est particulièrement importante à la fin de la saison sèche, en Septembre, Octobre et Novembre.

On aura une idée de son ordre de grandeur en notant qu'en Europe occidentale sa valeur mensuelle moyenne varie entre 0,40 et 0,50 et sa valeur annuelle entre 0,12 et 0,16.

Du fait de cette grande variabilité des précipitations il est difficile de distinguer la saison des pluies de la saison sèche. Pratiquement cette dernière se réduit à 4 mois : Août, Septembre, Octobre, et Novembre. La saison des pluies proprement dite s'étend de Janvier à Avril inclus et englobe en certains points une partie de Décembre.

Mai, Juin, Juillet, bien que figurant dans la saison humide théorique, constituent des mois de transition. On observe cependant à quelques endroits une curieuse recrudescence des précipitations en Mai ou en Juin et même en Juillet.

Cette manifestation est assez nette à Canala en Mai ; à Canala, Ponérihouen, Ouitchambo, Ouaménie et Voh en Juin ; et en Juillet à La Foa.

Par exemple à Canala en Mai, le facteur pluviométrique est de 128 à l'excès pluviométrique de + 43 ; à Ouaménie en Juin le facteur pluviométrique est de 117 et l'excès pluviométrique de + 35.

Les précipitations tombent en général sous forme de pluie ou d'averse ; la neige est inconnue même sur les sommets ; la bruine assez rare.

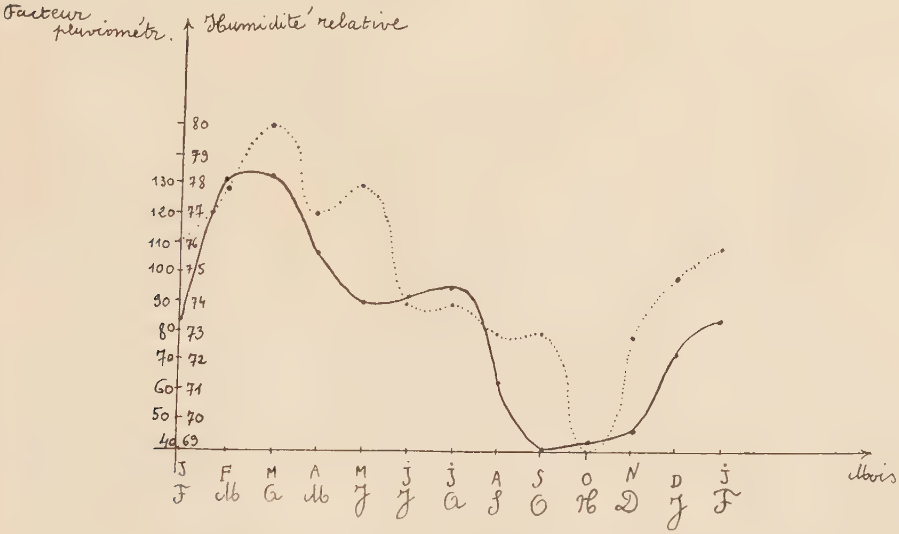

Fig. 2. Variations du facteur pluviométrique et de l'humidité relative avec le mois de l'année. Facteur pluviométrique en noir. Humidité relative en ponctué. Pour mettre en évidence le parallelisme des deux courbes la première a été décalée d'un mois en avance par rapport à la deuxième.

Nous n'avons pu étudier que pour Nouméa et dans l'intervalle de 4 ans 1935–1938 le nombre moyen de jours de pluie par mois et par an ainsi que la fréquence de certaines pluies donnant une hauteur d'eau déterminée en 24$^{\text{h}}$.

Cette statistique ne peut donc donner qu'un ordre de grandeur. D'après elle, il pleut à Nouméa en moyenne 125 jours par an. En Mars et Avril il pleut environ 1 jour sur deux, tandis que Septembre, Novembre et surtout Octobre ne possèdent qu'un petit nombre de jours de précipitation.

Pour tous les mois de l'année les pluies les plus fréquentes sont celles donnant une hauteur journalière comprise entre 1 et 4,9$^{\text{mm}}$, viennent ensuite celles comprises entre 5$^{\text{mm}}$ et 9$^{\text{mm}}$,9.

Les pluies donnant plus de 20$^{\text{mm}}$ d'eau ne sont pas rares 11,4% et sont réparties sur toute l'année.

Elles donnent une hauteur d'eau égale à 54% de la hauteur totale annuelle. Les pluies diluviennes sont donc assez fréquentes. Elles jouent un rôle important dans le régime hydrographique calédonien provoquant souvent et en toutes saisons des crues destructrices. Elles exoliquent également la grande variabilité mensuelle et annuelle du régime pluvial. Il serait intéressant de noter les intensités maxima par heure de précipitation effective, mais nous n'avons aucune indication à ce sujet.

De 1935 à 1938 les plus fortes chutes à Nouméa sont pour une durée de 24^{H} de 244^{mm},3 en Mars et de 236^{mm},0 en Novembre.

Pour la même période de 4 ans on note 350^{mm} à Plum, 455^{mm} à Canala; à Païta le pluviomètre déborde dans la nuit. A Yaté 2 journées consécutives de pluie donnent respectivement 405^{mm} et 646^{mm} en 24^{H}. Si on admet que la pluie a été ininterrompue durant 24^{h}, cela donne une moyenne horaire de 27^{mm} environ. De telles pluies saturent rapidement le sol et le coefficient d'écoulement devient très grand de sorte que l'eau ruisselle. Elles sont donc peu profitables à l'agriculture et dangereuses par la rapidité des crues qu'elles provoquent.

La hauteur moyenne des pluies à Nouméa par jour de pluie est de 8^{mm},29.

HUMIDITÉ

L'humidité relative et la tension de vapeur ont été calculées à Nouméa à l'aide du psychromètre depuis Janvier 1935.

Les archives donnent seulement les valeurs maxima et minima de l'humidité relative et non ces valeurs aux 3 heures synoptiques. La moyenne a donc été calculée comme la moyenne des deux valeurs extrêmes. Le tableau VII donne donc :

1) Les moyennes mensuelles et annuelles des minima et maxima journaliers de l'humidité relative.

2) Les moyennes mensuelles et annuelles de cette même humidité relative.

3) Enfin la tension moyenne de la vapeur d'eau pour l'année et pour chaque mois. Il a semblé inutile de donner les moyennes pour chaque heure synoptique, la tension variant peu au cours d'une même journée ; on est seulement parti d'une moyenne journalière, moyenne des 3 valeurs synoptiques.

La valeur moyenne mensuelle de l'humidité relative varie suivant les mois entre 69 et 80%. Elle est particulièrement faible à la saison sèche : en Septembre, Octobre, Décembre et surtout Novembre.

La moyenne annuelle est égale à 75%.

L'amplitude de la variation diurne mensuelle varie selon le mois entre 11 et 20%. Elle est donc relativement faible.

D'autre part l'humidité est toujours assez forte puisque la moyenne des minima atteint même à la saison sèche 64% en Août et Septembre, 66% en Octobre, 61% en Novembre.

La moyenne annuelle de la tension de vapeur est égale à 17^{mm},03. La moyenne mensuelle a, suivant les mois, une variation dans le même sens que la température moyenne. On peut noter que $\frac{Tm}{fm}$ varie peu avec le mois, on a en effet :

Janv.	Févr.	Mars	Avr.	Mai	Juin	Juil.	Août	Sept.	Oct.	Nov.	Déc.
1,29	1,25	1,31	1,30	1,41	1,33	1,50	1,50	1,51	1,44	1,45	1,36

Deux facteurs influent en sens inverse sur l'humidité relative : la variation de la température produit une variation en sens inverse de l'humidité relative et la variation de la pluviosité entraine une variation dans le même sens.

Or la saison sèche coïncidant en grande partie avec la saison froide et la saison humide avec la saison chaude, l'humidité relative moyenne est peu variable au cours de l'année. Cependant, il semble que l'influence de la pluviosité est prépondérante. Le parallélisme flagrant des courbes du facteur pluviométrique et de l'humidité relative en fonction du mois de l'année en fait foi. Cependant la courbe de l'humidité relative moyenne est décalée d'un mois en retard sur l'autre courbe.

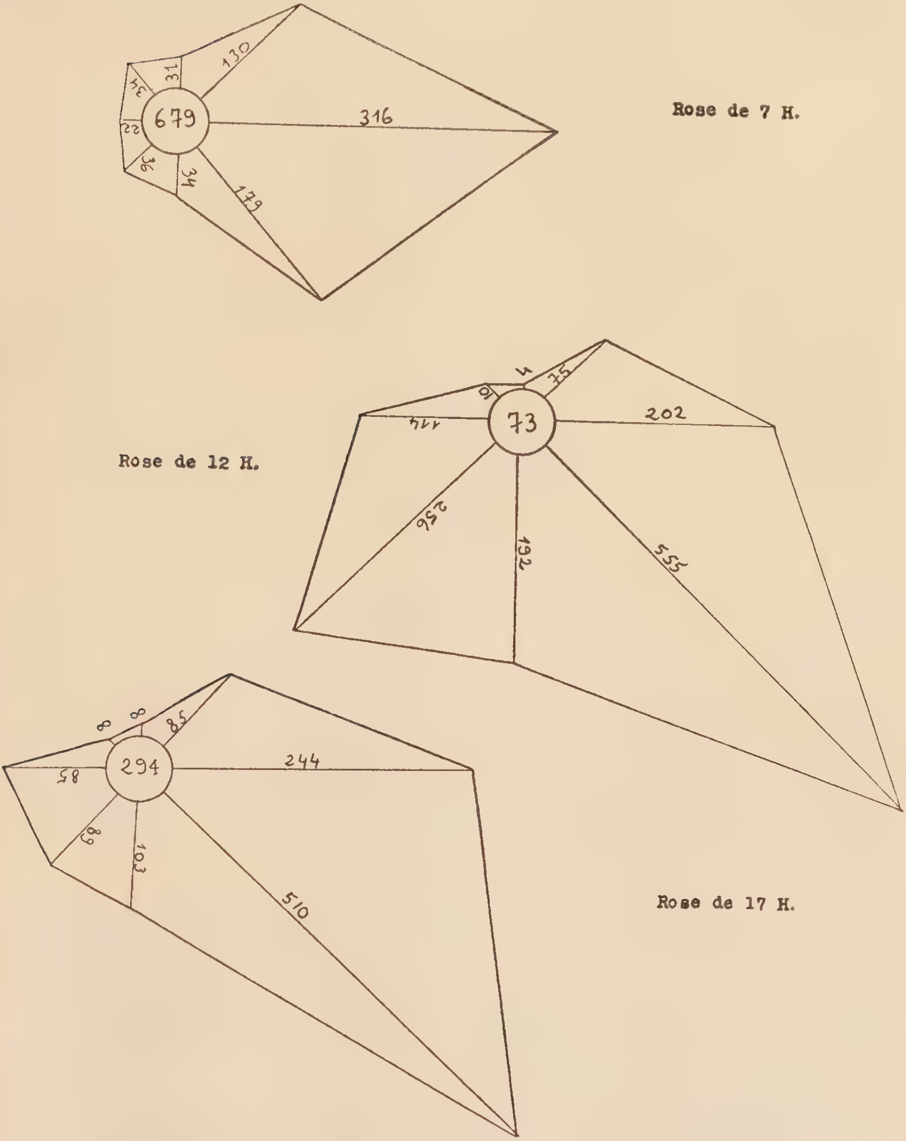

Fig. 3. Roses des vents pour l'année à Nouméa. (De 1935 à 1938.)

La tension de vapeur $f = \frac{Fe}{100}$ varie dans le même sens que la température, car *e* varie peu et la tension maxima F croit avec la température.

ÉVAPORATION

Des mesures d'évaporation ont été effectuées à Nouméa à l'aide de l'évaporomètre Piche sous abri en 1937 et 1938. La faible durée de ces observations ne permet pas de tirer des conclusions sur sa variation au cours de l'année. Le tableau VII donne les valeurs moyennes mensuelles et annuelle. Cette dernière est égale à 2^{mm},16 par jour. La moyenne mensuelle est maximum en Novembre avec 3^{mm},13 par jour.

Pression

Des mesures de pression sont effectuées à Nouméa depuis Janvier 1935 à l'aide d'un baromètre à mercure type Fortin. Les variations sont enregistrées à l'aide d'un baromètre enregistreur à ressort Richard.

Le tableau VIII donne les valeurs moyennes mensuelles et annuelles de la pression, ainsi que l'amplitude de chacune des deux oscillations journalières de jour et de nuit, leur somme et leur moyenne.

Toutes ces valeurs sont exprimées en millibars et centièmes.

Les pressions sont calculées avec touts les corrections habituelles : correction instrumentale, réduction à 0° centigrade, au niveau de la mer et à la gravité normale (altitude 0, latitude 45°).

La moyenne annuelle de la pression est égale à 1012,12 millibars. Elle est donc assez élevée. Les moyennes mensuelles croissent à peu près régulièrement de Janvier : 1007,20^{mb} à Juin 1015^{mb},07 ; elles varient peu de Juin à Septembre où elles oscillent entre 1014,31 et 15,92. Puis elles décroissent de nouveau jusqu'à Janvier. Il y a donc une oscillation simple annuelle. Nous verrons lors de l'étude des vents au sol comment nous devons interpréter ces résultats.

La variation diurne présente la double oscillation classique. L'amplitude moyenne de la variation de nuit est plus faible que celle de jour 1^{mm},34 contre 2^{mm},71. L'amplitude moyenne des deux oscillations varie peu avec la saison : 1^{mb},71 en Février contre 2^{mb},25 en Novembre. La moyenne annuelle est de 2^{mb},02 ; elle est du même ordre de grandeur que celle observée dans les pays de même latitude.

Bien que la pression moyenne soit en général élevée, elle peut parfois atteindre des valeurs anormalement basses au passage d'un cyclone sur ou au voisinage de l'île. On peut citer le cas du 24 Mars 1937, 981^{mb} à Nouméa, du 25 Mars 1939, 974^{mb} aux îles Bélep et surtout la dépression record observée à Nouméa en 1857 par Bouquet de la Grye : 945^{mb}.

Vent au Sol

De mesures de vent au sol figurent aux archives de la Colonie depuis Janvier 1935. Ces archives contiennent les directions et vitesses de vent exprimées dans l'échelle Beaufort pour les 3 heures synoptiques de la journée. Nous donnons pour chacune de ces heures un tableau indiquant le nombre d'observations de chacune des 8 directions fondamentales, le nombre des vents calmes, le nombre d'observations total, le nombre de vents d'E. et de S-E réunis, le pourcentage de ces vents calmes par rapport au nombre total d'observations. (Voir tableaux IX, X, XI.)

D'autres tableaux (XII, XIII, XIV) donnent pour chaque heure synoptique la vitesse moyenne et le nombre d'observations de chacune des forces Beaufort de 1 à 9.

Enfin, des roses de fréquence montrent la variation diurne et annuelle de la direction du vent.

Au cours de l'année, les vents les plus fréquents sont les vents d'E et de SE. A 7^{H}, 63% des vents non calmes sont de SE ou d'E, à 12^{H} 53% et à 17^{H} 67%. La Nouvelle-Calédonie est donc soumise au régime des alizés.

Il existe une variation diurne très marquée dans la direction du vent. Elle est produite par la brise de mer et la brise de terre. A 7^{H} on peut admettre que le vent est le vent isobarique ; les vents de secteur E dominent, puis les vents de SE, puis de NE. Au cours de la matinée la brise de mer se lève. Elle est de SW et vient se composer vectoriellement avec le vent isobarique. Il en résulte

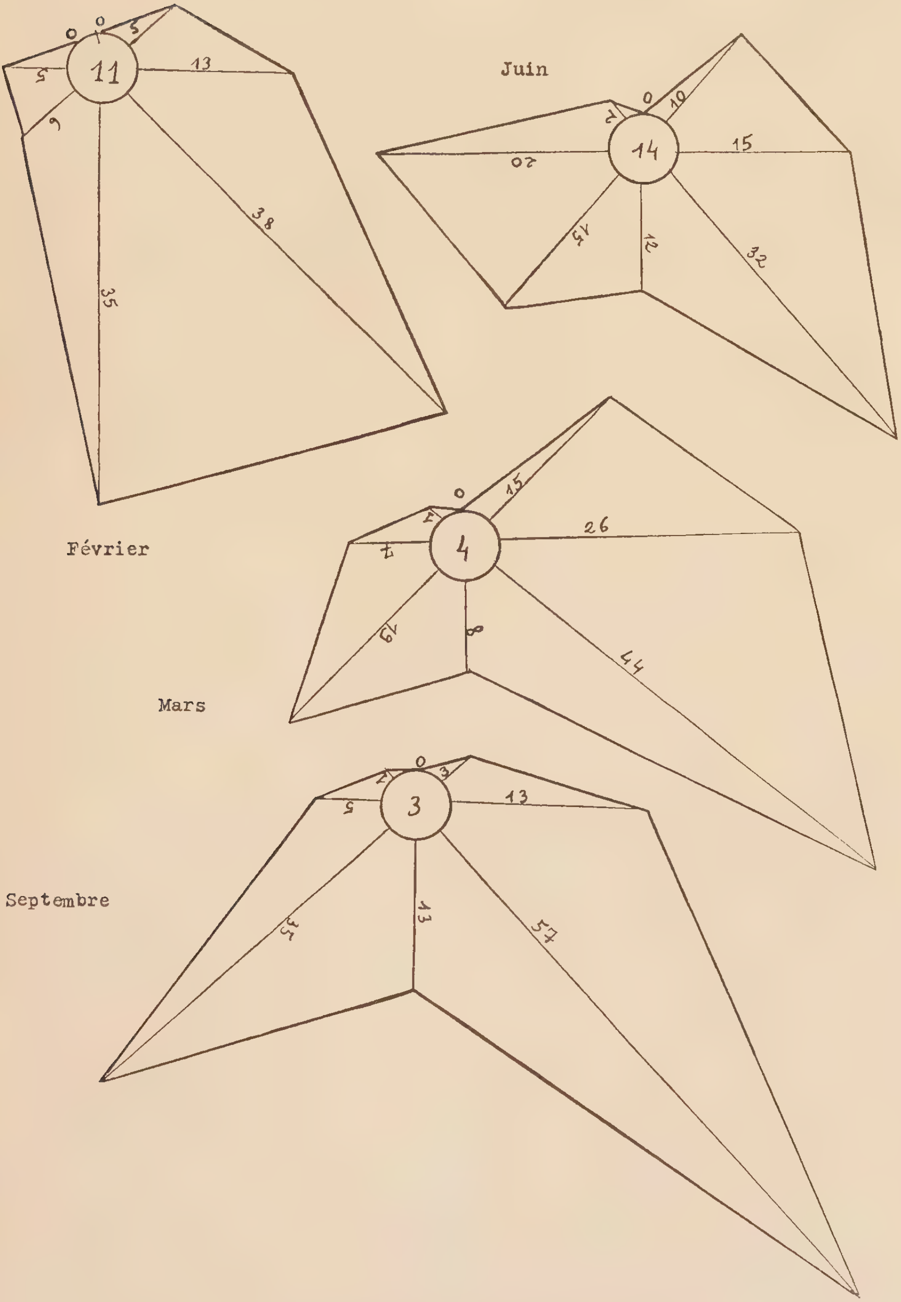

Fig. 4. Roses des vents mensuelles à Nouméa (12 H.) pour divers mois de l'année (années 1935–1938).

une rotation générale des vents vers le SW, dans le sens des aiguilles d'une montre si le vent à 7^{H} est entre NNE et SW, dans le sens inverse s'il est entre NNW et SW. Si le vent isobarique est nul, à 12^{H} le vent est de SW alors, qu'il était calme à 7^{H}.

A 12^{H} les vents dominants sont donc les vents de SE (rotation des vents d'E), suivis des vents de SW (rotation des vents de SE et de S, vents calmes), puis des vents de S (rotation des vents de SE), puis d'E (rotation des vents de NE). Dans l'aprèsmidi, la brise de mer continue, puis faiblit pour faire place, à la nuit, à la brise de terre de NE. D'où rotation des vents, vers le NE et augmentation des vents de NE. A 17^{H} le phénomène n'a pas pris sa pleine extension, cependant le nombre des vents d'E a augmenté (par rapport à 12^{H}) au détriment des vents de SE, les vents de S, SW, W ont diminué, les vents de NE ont augmenté. Il est à présumer que la nuit, les vents d'E à NE sont dominants, ceux d'entre S et W très rares.

Il existe également une importante variation annuelle dans le régime des vents et cette variation est en relation directe avec les variations annuelles de la pression et le régime pluvial. La Nouvelle-Calédonie subit l'influence du vaste continent australien dont la présence vient perturber la régularité du régime des alizés. Par suite du contraste thermique entre l'océan et l'intérieur des terres, l'Australie joue le rôle de centre d'action.

Durant la saison froide, l'Australie constitue un centre anticyclonique. La Nouvelle-Calédonie se trouve en bordure N de la zone de hautes pressions qui entoure le globe terrestre d'une manière continue de part et d'autre du 30° parallèle. La Nouvelle-Calédonie étant en situation anticyclonique, les pluies sont rares, c'est la saison sèche. Nouméa se trouve à l'extrêmité orientale de la crête anticyclonique ayant l'Australie comme centre à l'endroit où la rotation de SW à SE s'effectue. Les alizés d'E à SE sont dominants. Si on considère les vents à 17^{H} qui sont les moins troublés par la variation diurne, 60% sont entre E et SE, mais 24% sont entre SW et W.

Pendant la saison chaude au contraire l'Australie constitue une zone dépressionnaire, en bordure de laquelle se trouve la Nouvelle-Calédonie.

La pression moyenne s'abaisse vers 1007^{mb} en Janvier.

La ceinture de hautes pressions ininterrompue à la saison froide tout autour du globe, se trouve ainsi scindée en Australie (comme à l'extrêmité de l'Afrique et de l'Amérique du Sud). Les vents tournent autour du continent australien dans le sens des aiguilles d'une montre, mais sont nettement convergents. Le contact de masses froides d'W et de masses chaudes de NE donne de nombreuses précipitations en particulier en Nouvelle-Calédonie, c'est la saison des pluies.

Les alizés d'E à SE sont encore dominants 71%, mais les vents d'W à SW sont devenus très rares 8% seulement.

Par contre, les vents entre E et N n'ont pas augmenté sensiblement.

La force du vent subit une variation diurne marquée. Elle croit jusqu'aux environs de 12^{H} et décroit ensuite jusqu'à la nuit.

Au cours de l'année, la force moyenne des vents au cours de la période d'Avril à Septembre est plus faible que celle des autres mois de l'année.

Les vents de force 2 (échelle Beaufort) sont les plus fréquents à toute heure de la journée et en toute saison. Les vents calmes nombreux à 7^{H} 46% sont rares à 12^{H} 5% seulement. Leur nombre augmente à 17^{H} jusqu'à 20%.

Les vents violents de force supérieure ou égale à 5 Beaufort sont rares 1,6%, ceux très violents (force supérieure ou égale à 7 Beaufort exceptionnels 0,16%. Ils n'existent qu'à la saison des cyclones.

VENTS EN ALTITUDE

Aucune mesure de vent en altitude n'a été effectuée en Nouvelle-Calédonie.

On peut cependant constater par des observations néphosco piques l'existence d'un contre-alizé du NW se manifestant en certains cas par le déplacement de cirrus ou cirrocumulus élevés. On peut donc dire qu'il y a un contre-alizé à hauteur de ces nuages, soit 6000 à 8000^m. Mais on ne connaît pour l'instant ni son altitude inférieure, ni sa vitesse, ni ses variations saisonnières.

On peut espérer que des renseignements sur ce sujet seront fournis prochainement par les sondages aérologiques qui vont débuter bientôt.

NEBULOSITÉ

Des observations de nébulosité ont été effectuées d'une manière suivie à Nouméa depuis 1935. Le tableau XV indique pour chaque mois et pour l'année la nébulosité moyenne, le nombre de jours clairs (nébulosité 0 à 2/10), peu

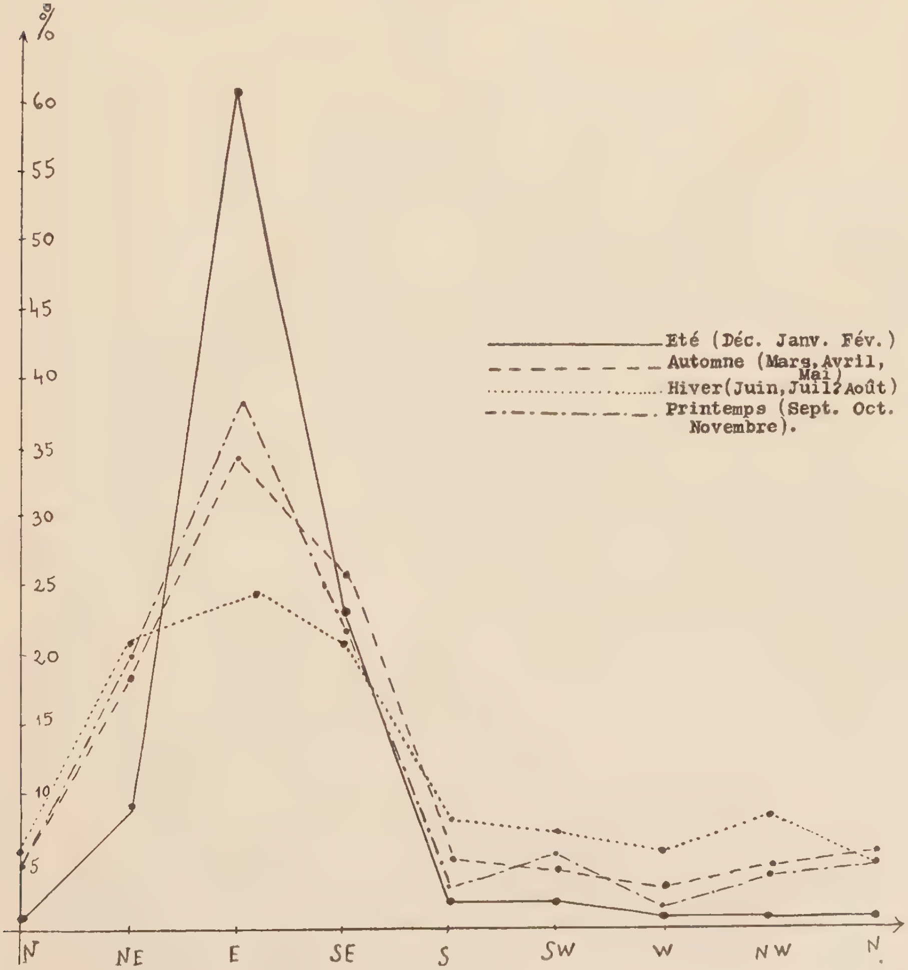

Fig. 5. Percentage des observations de vent de chaque secteur à Nouméa de 1935 à 7 H.

nuageux (2 à 5/10) nuageux (5 à 8/10) ou couverts (8 à 10/10) pour cet intervalle de 4 ans.

La nébulosité moyenne est de 5,0/10. Elle est donc assez faible. Le nombre de jours clairs est de 72,25 par an, le nombre de jours couverts de 73,50 par an.

Les mois de Mars et d'Avril semblent ceux dont la nébulosité moyenne est la plus forte; ceux de Septembre, Octobre, Novembre (saison sèche) la plus faible. Elle varie de 6,3/10 en Mars et Avril à 4,3/10 en Octobre. Les jours couverts sont particulièrement nombreux en Mars et Avril et rares en Septembre, Octobre, Novembre. Le nombre des jours clairs semble suivre au cours de l'année une marche assez fantaisiste et aucune loi ne semble présider à leur distribution.

HAUTEUR DES NUAGES

Aucune mesure de plafond n'a été faite de manière suivie en Nouvelle-Calédonie. Il semble cependant que les plafonds bas par stratus ou stratocumulus, si fréquents dans les régions tempérées, soient à peu près inconnus à Nouméa. Par contre, des plafonds de 200 à 300^{m} peuvent exister en période de pluie au passage d'une discontinuité, bouchant les sommets aux environs de Nouméa.

VISIBILITÉ

Des mesures de visibilité ont été effectuées à Nouméa d'une manière continue depuis Janvier 1935. Le tableau XVI donne les visibilités moyennes aux 3 heures synoptiques, ainsi que la moyenne de ces 3 valeurs. Les tableaux XVII, XVIII, XIX donnent la fréquence des visibilités comprises entre certaines limites aux 3 heures synoptiques. Enfin le tableau XX donne le nombre moyen par an de jours de brouillard (visibilité inférieure à 1^{Km}) pour chaque mois et pour l'année.

D'une manière générale pour Nouméa la visibilité est excellente. La visibilité moyenne est égale à $18^{Km}6$. Elle est maximum vers 12^{H} : $20^{Km},7$ à 12^{H}. Elle est surtout grande en Janvier et Février : $24^{Km},5$ et $26^{Km}8$, mais elle ne descend pas au-dessous de $12^{Km},8$ en Juin. Les visibilités exceptionnelles (supérieures à 50^{Km}) ne sont pas rares surtout le matin et vers midi. Il y en a en moyenne à 7^{H} 40 par an, à 12^{H} 42, à 17^{H} 29.

Les mauvaises visibilités sont par contre peu fréquentes. On compte en moyenne 2,1 observations de visibilité inférieures à 1^{Km} par an et 23,3 observations de visibilités entre 1 et 4^{Km}. On les rencontre surtout le matin et le soir, rarement vers midi. Elles sont surtout fréquentes en Mars et Avril. Il semble d'ailleurs, sans qu'on puisse donner une valeur chiffrée, que la plupart de ces faibles visibilités sont dues non à des brouillards ou à des brumes proprement dits, mais à des abaissements de visibilité provenant de précipitations abondantes.

Quoiqu'il en soit à Nouméa et plus généralement sur toute la côte, la limpidité de l'air est remarquable, ainsi que sa pureté. En effet, sur le nombre total de jours où l'humidité relative a atteint 90 à 95%, 12,7% d'entre eux seulement ont été des jours où la visibilité a atteint une valeur inférieure à 4^{Km} et 23,4% des jours où l'humidité relative à atteint 95 à 100% ont été des jours de brume. Cela implique la rareté des noyaux de condensation et la pureté de l'atmosphère même dans ses basses couches.

Pour cette raison et également pour sa faible nébulosité moyenne, Nouméa ou un autre point de la côte calédonienne pourrait être le siège d'un observatoire astronomique.

Par contre, certaines plaines de l'intérieur et en particulier Bourail et La Foa, sont sujettes à de fréquents brouillards.

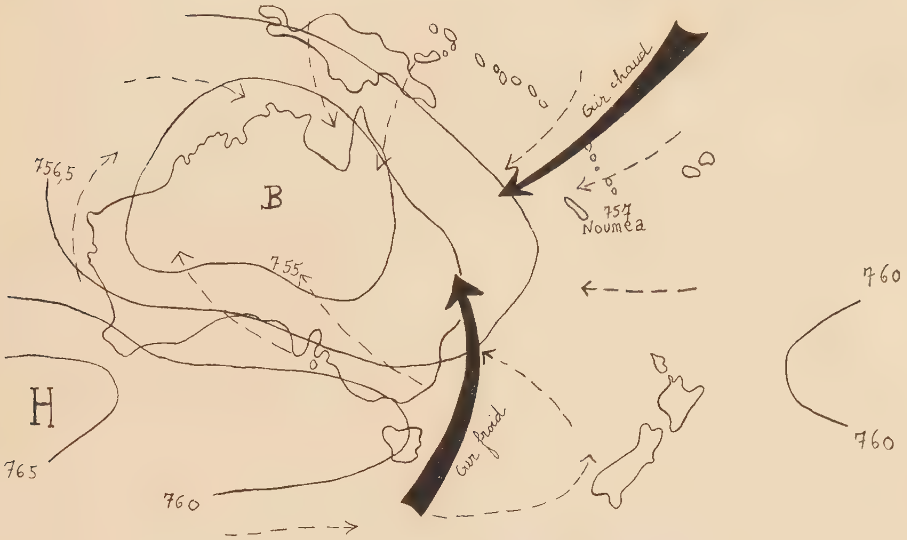
756,5
B
755
Air chaud
757
Nouméa
760
760
H
765
760
Air froid

Fig. 6. Isobares moyennes de la saison chaude (Janvier).

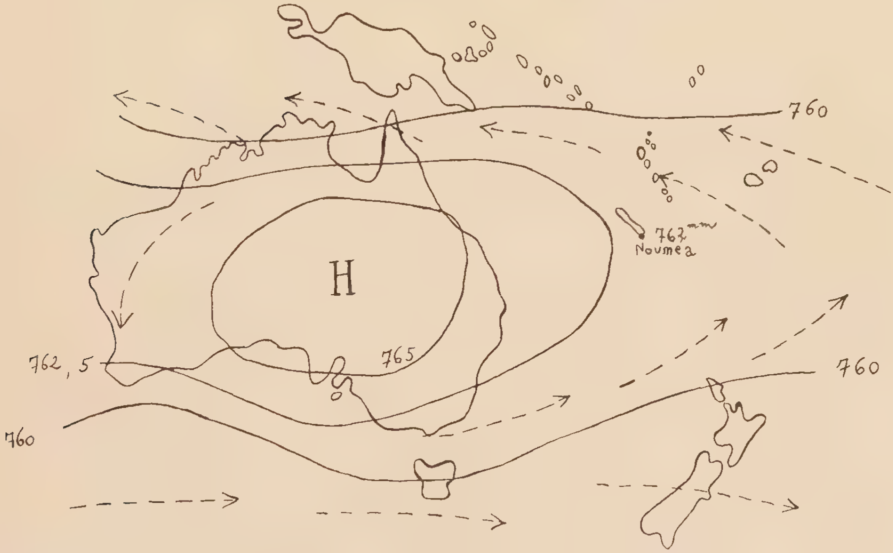
760
762mm
Noumea
H
765
762, 5
760
760

Fig. 7. Isobares moyennes de la saison froide (Juillet).

ORAGES

Les manifestations électriques: orages, éclairs, tonnerres sont rares en Nouvelle-Calédonie. On en compte en moyenne 9 par an à Nouméa et plus particulièrement à la saison des pluies en Décembre, Janvier, Février. Ils semblent véritablement exceptionnels à la saison sèches: 4 en 4 ans de Juin à Octobre.

Les chutes de grêle sont encore plus rares. On n'en compte pas une seule en 4 ans à Nouméa.

Seismes

En Nouvelle-Calédonie il n'existe aucun seismographe. Les secousses de faible intensité ne peuvent donc être décelées. Cependant quelques secousses sont ressenties chaque année par les Calédoniens. Il faut donc que leur amplitude ou leur accélération soit forte. Il est probable que leur épicentre est situé aux Nouvelles-Hébrides où les séismes sont fréquents sans être trés destructeurs. Il serait intéressant d'installer un séismographe à Nouméa, à proximité des Nouvelles-Hébrides et non loin du Japon, de la-Nouvelle-Zélande et des Indes Néerlandaises. Nous n'osons espérer que la prochaine installation à Nouméa d'un baromètre à poids moyen modèle puisse permettre une étude approfondie de ces phénomènes.

Signalons pour terminer et à titre documentaire que plusieurs colons hébridais signalent une recrudescence d'activité du volcan Ambrym peu de temps après des pluies diluviennes, ce qui confirmerait l'hypothèse qui fait jouer un rôle, peut être secondaire, aux eaux d'infiltration dans les éruptions volcaniques.

Les Cyclones en Nouvelle-Calédonie

Des cyclones touchent fréquemment la Nouvelle-Calédonie entre Décembre et Avril. Ils provoquent d'importants dégâts, mais en général font peu de victimes en raison de la barrière de récifs qui entoure l'île d'une ceinture presque continue et empêche le ras-de-marée, si meurtrier dans d'autres contrées exposées aux typhons.

Les renseignements statistiques figurant dans la présente étude ont été tirés de "Australian Hurricanes and Related Storms" de H. A. Hunt et complétés 1) par l'ouvrage de M. Sanson pour le cyclone du 11 Janvier 1857, 2) par les notes du Docteur Mialaret pour la période de 1908 à 1913, 3) par la carte de la société "Le Nickel" donnant des trajectoires de 1910 à 1932, 4) par les notes de Monsieur Schmidt pour la période 1935–1939.

Ces archives indiquent 60 cyclones ayant intéressé la Nouvelle-Calédonie; qu'ils soient passés sur elle ou à proximité immédiate. Bien entendu on ne saurait affirmer que ce nombre est le nombre de cyclones ayant intéressé la Nouvelle-Calédonie depuis 1847, année où le premier d'entre eux fut signalé. Il est infiniment probable que certains d'entre eux passèrent inaperçus ou ne furent pas signalés dans les annales météorologiques, tandis qu'au contraire de simples bourrasques furent confondues avec un cyclone tropical. Quoiqu'il en soit sur 60 cyclones signalés, 23% ont eu lieu en Janvier, 27% en Février, 25% en Mars, 5% en Avril, et 10% en Décembre, ce qui donne pour la période de Décembre à Avril 90%, ce qui laisse un pourcentage égal à 10% pour les autres mois. Encore n'est-il pas certain que les cyclones observés en Mai, Juin, Septembre, Octobre soient de véritables cyclones tropicaux.

L'un d'eux aurait sévi à Lifou un 26 Septembre entre 1851 et 1859, la date est incertaine et l'autorité le signalant inconnue. Celui du 28 Juillet 1919 est passé entre la Calédonie et le Queensland, il ne nous a donc pas intéressés directement. Celui du 28 au 30 Octobre 1919 est donné comme "Coup de vent."

Le coup de vent du 26 Mai 1935 est produit par une dépression centrée entre Lord Howe et Norfolk et se dirigeant vers SE, d'après le service australien.

Le cyclone du 9 Juillet de la même année est centré près de Rockhampton (Queensland) se dirigeant vers le SE également. Si on fait abstraction de ces 5 "cyclones" qui sont soit incertains, soit éloignés de la Nouvelle-Calédonie, le pourcentage des cyclones dans la période de Décembre à Avril passe de 90% à 98%. Quoiqu'il en soit, on peut dire que l'immense majorité des cyclones intéresse la Nouvelle-Calédonie entre le ler Décembre et le 15 Avril. Il semble

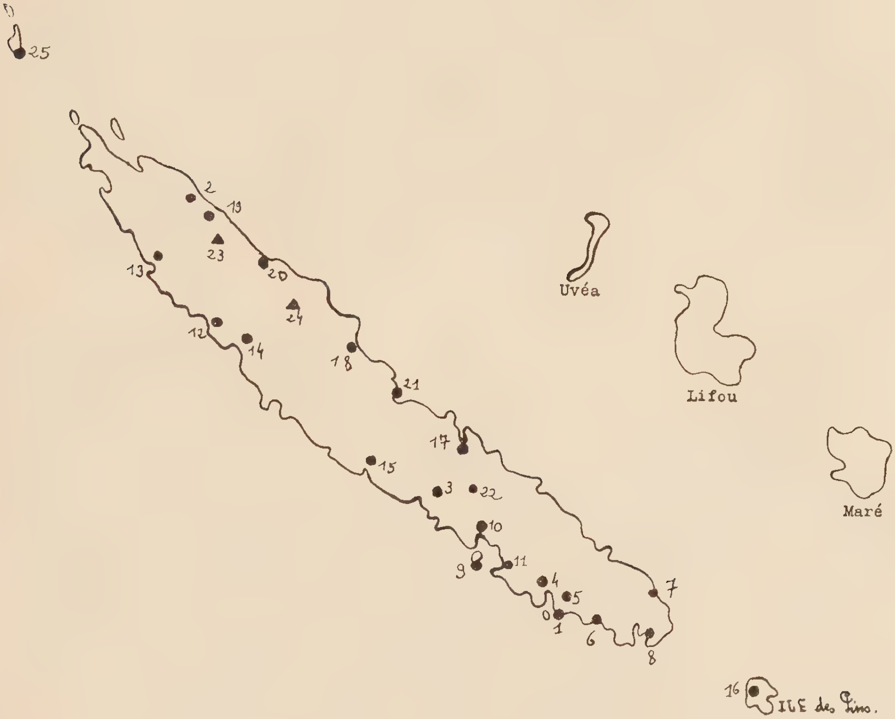

Fig. 8. Carte de la Nouvelle-Calédonie. 1, Nouméa; 2, Pouébo; 3, La Foa; 4, Païta; 5, Dumbéa; 6, Plum; 7, Yaté; 8, Prony; 9, Ile Parceval; 10, Ouaménie; 11, Tembia; 12, Voh; 13, Gomen; 14, Koné; 15, Bourail; 16, Vao; 17, Canala; 18, Ponérihouen; 19, Oubatche; 20, Hienghène; 21, Houaïlou; 22, Col d'Amieu; 23, Mont-Panié; 24, Mont Tchingu; 25, Iles Bélep.

que les cyclones tropicaux intéressant la Nouvelle-Calédonie aient pour la plupart leur origine entre le 165^e degré et le 175^e degré de longitude Est et le 7^e et 10^e parallèle Sud, légèrement au Nord des Banks et de l'Archipel de Torrès. Quelques-uns semblent prendre naissance dans la région de Santo dans l'Archipel des Nouvelles-Hébrides. La trajectoire a un aspect vaguement parabolique. Le cyclone se dirige d'abord vers le S ou SW puis il s'incurve aux environs du tropique, et tourne à SE ou E. Il aborde en général l'île venant du N ou du NE. Naturellement il ne faudrait pas tabler avec certitude sur une telle trajectoire, on pourrait s'exposer à de cruels mécomptes.

Car il existe des trajectoires plus complexes que l'on ne peut mettre en évidence que par une étude approfondie des cartes quotidiennes.

La vitesse de déplacement du cyclone est variable, 30 à 40^{Km}, mais assez faible. Elle diminue notablement vers le sommet de la trajectoire.

L'approche d'un cyclone est marquée par une forte houle venant du centre du cyclone; malheureusement elle ne peut être observée sur la côte en raison de la barrière de récifs qui la brise et modifie sa direction. Elle est observée par contre en mer où, d'après des observateurs dignes de foi, elle précède le cyclone de 6 à 12 heures. Aucune mesure de l'agitation microséismique n'a été effectuée jusqu'à ce jour. Sur les causes du phénomène nous ne pouvons rien dire de précis puisqu'aucune carte météorologique n'a été tracée en Nouvelle-Calédonie. Il semble cependant que le cyclone tropical est dû à une ondulation du front équatorial séparant l'air équatorial, qui joue le rôle de masse chaude, de l'air tropical, qui joue le rôle de masse froide, cette ondulation ayant atteint le stade de l'occlusion. Faut-il admettre que cette ondulation est produite par un brusque afflux d'air froid de composante Sud, provoquant une hausse de pression aux latitudes tropicales et donnant une impulsion au front principal quasi-stationnaire ? C'est ce qu'une longue étude des cartes pourrait seule nous dire. Quoiqu'il en soit une forte hausse de pression a été plusieurs fois enregistrée à Nouméa, quelques jours avant l'arrivée d'un cyclone.

Des ondulations du front polaire peuvent également atteindre la Nouvelle-Calédonie et y donner des bourrasques ou tempêtes d'origine toute autre que celle des cyclones tropicaux avec lesquels elles sont souvent confondues.

CONCLUSION

La Nouvelle-Calédonie possède un climat heureux, chaud sans excès, pas très humide, ensoleillé. Une légère brise presque continuelle y rend les chaleurs de la saison chaude supportables. L'Européen s'y acclimate parfaitement et la Nouvelle-Calédonie pourrait être pour la France une colonie de peuplement.

Pour terminer cette étude sommaire, nous ne saurions trop insister encore une fois sur le caractère provisoire de ses conclusions. Nous espérons que le Service Météorologique pourra d'ici quelques années donner des valeurs plus précises des moyennes climatologiques et fournir sa contribution à l'étude dynamique de cette région par des mesures sur le régime des contre-alizés et l'application des théories norvégiennes à la prévision des cyclones. C'est dans cette voie qu'il s'efforcera, dans la mesure de ses moyens, de travailler.

TABLEAU I

Temperature a Nouméa

Mois	Moyennes mensuelles et annuelles	Anomalie moyenne	Moyennes extrêmes		Moyennes amplitudes à périodiques	Moyennes des extrêmes mensuels et annuels		Extrêmes absolus		Moyennes de 17 ans[a]
			Min.	Max.		Min.	Max.	Min.	Max.	
Janvier	26.80	0.31	26.44	27.22	7.54	19.25	34.05	18.0	34.6	25.25
Février	26.91	0.38	26.54	27.67	7.73	20.25	33.52	18.8	35.5	25.57
Mars	25.92	0.42	25.43	26.41	6.39	19.30	32.15	18.0	33.4	25.07
Avril	24.62	0.63	23.74	25.90	6.01	18.70	30.25	16.8	31.4	23.71
Mai	22.64	0.47	22.00	23.58	6.61	15.60	28.60	14.8	29.4	21.34
Juin	21.34	0.38	20.95	21.86	6.31	15.00	27.05	14.4	27.6	19.91
Juillet	20.00	0.31	19.50	20.51	6.98	12.70	26.85	12.2	28.2	19.24
Août	20.19	0.26	19.89	20.52	7.26	13.45	27.90	13.0	28.4	18.87
Septembre	20.81	0.44	20.37	21.40	8.00	13.15	28.40	12.2	29.4	20.48
Octobre	23.02	0.15	22.75	23.23	7.94	16.10	30.15	15.2	32.0	21.69
Novembre	24.28	0.56	23.16	24.94	8.12	17.00	32.30	15.2	33.0	23.35
Décembre	25.71	0.19	25.46	25.95	7.69	18.95	33.60	17.4	34.2	24.73
Année	23.53	0.21	23.31	23.82	7.21	12.55	34.12	12.2 (le 31.7 35) (le 5 9.35)	35.5 (le 9.2 35)	22.43

[a] Pour l'ensemble de la Colonie.

TABLEAU II

Hauteurs de Pluie à Voh (Côte Ouest), Moyennes de 23 Ans (1913 à 1938 sauf 32-33-34)
(En millimètres et dixièmes)

Mois	Moyenne	Facteur pluvio-métrique	Pourcentage uniforme	Quotient pluvio-métrique	Excès pluvio-métrique
Janvier	135,7	156	85	1,84	+71
Février	117,8	135	77	1,75	+58
Mars	89,5	103	85	1,21	+18
Avril	61,3	70	82	0,85	−12
Mai	72,5	83	85	0,98	− 2
Juin	75,7	87	82	1,06	+ 5
Juillet	68,5	78	85	0,92	− 7
Août	47,5	54	85	0,64	−31
Septembre	31,2	36	82	0,44	−46
Octobre	41,3	47	85	0,55	−38
Novembre	30,2	35	82	0,43	−47
Décembre	101,4	116	85	1,36	+31
Année	872,6	1000	1000	1,00	00

TABLEAU III

Hauteurs de Pluie à Yaté (Côte Sud-Est), Moyennes de 19 Ans
(de 1911 à 1920 et de 1930 à 1938)
(En millimètres et dixièmes)

Mois	Moyenne	Valeurs extrêmes		Facteur pluvio-métrique	Pour-centage uniforme	Quotient pluvio-métrique	Excès pluvio-métrique
		Min.	Max.				
Janvier	419,4	92,3	1066,0	124	85	1,46	+39
Février	324,4	114,0	536,5	96	77	1,26	+19
Mars	499,8	177,3	973,8	148	85	1,74	+63
Avril	392,3	49,0	984,0	116	82	1,41	+34
Mai	258,4	24,5	719,0	76	85	0,89	− 9
Juin	208,9	20,0	598,7	62	82	0,76	−20
Juillet	251,5	10,0	568,4	74	85	0,88	−11
Août	173,9	27,9	487,0	51	85	0,60	−34
Septembre	165,3	9,2	580,2	49	82	0,59	−33
Octobre	208,3	8,5	543,5	62	85	0,73	−23
Novembre	193,3	1,5	1387,7	57	82	0,70	−25
Décembre	287,6	23,5	728,5	85	85	1,00	00
Année	3383,1	2149,0	4960,0	1000	1000	1,00	00

TABLEAU IV

Hauteurs de Pluie à Nouméa, Moyennes de 35 Ans (de 1903 à 1938, 1929 Excepté)

(En millimètres et dixièmes)

Mois	Moyenne	Valeurs extrêmes[a]		Facteur pluviométrique	Pourcentage uniforme	Quotient pluviométrique	Excès pluviométrique
		Min.	Max.				
Janvier	90,8	4,2	119,0	85	85	1,00	00
Février	139,9	14,4	211,8	132	77	1,71	+55
Mars	140,9	18,0	364,1	133	85	1,56	+48
Avril	113,8	19,6	272,6	107	82	1,30	+25
Mai	95,2	27,9	232,0	90	85	1,06	+ 5
Juin	96,9	15,5	176,8	91	82	1,11	+ 9
Juillet	101,0	25,5	267,8	95	85	1,12	+10
Août	69,1	18,2	115,8	64	85	0,75	−21
Septembre	42,0	5,3	164,4	40	82	0,49	−42
Octobre	45,5	1,2	148,1	43	85	0,50	−42
Novembre	48,4	4,0	392,2	46	82	0,56	−36
Décembre	78,4	7,0	180,5	74	85	0,87	−11
Année	1061,9	599,0	1638,8	1000	1000	1,00	00

[a] de 1924 à 1938.

TABLEAU V

Fréquence des Pluies d'Intensité Donnée à Nouméa de 1935 à 1938

Mois	Nombre total de jours de pluie[a]	Nombre moyen de jours de pluie[a]	Probabilité	Fréquence en %								Hauteurs en mm & supérieure à 200 mm
				0 mm 1 à 0 mm 9	1 mm à 4 mm 9	5 mm à 9 mm 9	10 mm à 19 mm 9	20 mm à 49 mm 9	50 mm à 99 mm 9	100 mm à 200 mm	Au-dessus de 200 mm	
Janvier	34	8.5	0.27	2.9	32.3	29.4	20.6	11.8	2.9	0.0	0.0	
Février	35	8.5	0.30	5.7	40.0	25.7	14.3	5.7	8.6	0.0	0.0	
Mars	62	15.5	0.50	9.7	38.6	27.4	8.1	12.9	1.6	0.0	1.6	244.3
Avril	63	15.5	0.52	12.7	35.0	22.2	19.1	9.5	1.6	0.0	0.0	
Mai	49	12.3	0.40	16.3	51.0	18.4	14.3	0.0	0.0	0.0	0.0	
Juin	42	10.5	0.35	14.3	45.2	16.7	14.3	9.5	0.0	0.0	0.0	
Juillet	40	10.0	0.32	15.0	32.5	20.0	17.5	12.5	2.5	0.0	0.0	
Août	47	11.8	0.38	25.6	57.5	2.1	4.3	8.5	2.1	0.0	0.0	
Septembre	32	8.0	0.27	34.4	43.8	9.4	6.2	3.1	3.1	0.0	0.0	
Octobre	22	5.5	0.18	27.2	45.4	9.1	4.5	13.6	0.0	0.0	0.0	
Novembre	30	7.5	0.25	16.7	36.6	26.6	10.0	0.0	6.7	0.0	3.3	236.0
Décembre	44	11.0	0.36	20.4	43.1	9.1	11.4	11.4	4.5	0.0	0.0	
Année	500	124.6	0.34	16.0	41.8	18.4	12.4	8.4	2.6	0.0	0.4	

[a] Plus de 0 mm 1.

TABLEAU VI

Pourcentage des Hauteurs d'Eau Fournies par des Pluies d'Intensité Journalière[a] Donnée à Nouméa de 1935 à 1938

Mois	de 20 mm à 49 mm,9	de 50 mm à 99 mm,9	au-dessus de 100 mm	Total
Janvier	31	16	00	47
Février	10	53	00	63
Mars	34	7	28	69
Avril	27	21	00	48
Mai	00	00	00	00
Juin	30	28	00	58
Juillet	32	21	00	53
Août	46	18	00	64
Septembre	12	34	00	46
Octobre	64	00	00	64
Novembre	00	25	46	71
Décembre	42	25	00	67
Année	27	21	6	54

[a] Par rapport à la hauteur moyenne totale par an ou par mois.

TABLEAU VII

Humidité Relative à Nouméa de 1935 à 1938 et Evaporation sous Abri de 1937 à 1938

Mois	Humidité relative moyenne			Tension de vapeur[b]	Evaporation moyenne[c]
	Min.	Max.	Moyenne[a]		
Janvier	70	81	75	20,72	2,52
Février	70	83	76	21,43	2,01
Mars	70	86	78	19,73	2,17
Avril	71	88	80	18,79	1,50
Mai	67	86	77	15,91	1,96
Juin	69	86	78	16,06	1,60
Juillet	65	83	74	13,25	2,05
Août	64	84	74	13,42	2,00
Septembre	64	82	73	13,65	1,90
Octobre	66	80	73	15,93	2,59
Novembre	61	76	69	16,69	3,13
Décembre	66	79	73	18,75	2,60
Année	67	83	75	17,03	2,16

[a] Obtenue en prenant la demi-somme du minimum et du maximum.
[b] Moyenne en millimètres et dixièmes.
[c] Moyenne diurne mensuelle et annuelle en millimètres et centièmes.

TABLEAU VIII

Pression à Nouméa (Toutes Corrections Effectuées) de 1935 à 1938
(En millibars et centièmes)

Mois	Pression moyenne	Amplitude variation diurne			
		Nuit	Jour	Total	Moyenne
Janvier	1007,20	1,54	2,34	3,88	1,94
Février	1007,71	0,97	2,44	3,41	1,71
Mars	1009,27	1,26	2,34	3,60	1,80
Avril	1001,57	1,27	2,68	3,95	1,96
Mai	1014,00	1,13	2,74	3,87	1,93
Juin	1015,07	1,17	2,72	3,89	1,94
Juillet	1014,31	1,31	2,76	4,07	2,03
Août	1015,59	1,37	2,88	4,25	2,12
Septembre	1015,92	1,32	3,09	4,41	2,20
Octobre	1014,41	1,34	3,07	4,41	2,20
Novembre	1011,26	1,68	2,83	4,51	2,25
Décembre	1009,20	1,77	2,58	4,35	2,17
Année	1012,12	1,34	2,71	4,05	2,02

TABLEAU IX

VENT AU SOL À NOUMÉA À 7 HEURES DE 1935 À 1938

Mois	N	NE	E	SE	S	SW	W	NW	Calme	Total	Vents non calmes	Vents d'E et de SE (total)	Pourcentage des vents d'E et SE[a]	Pourcentage des vents calmes[b]
Janvier	..	6	54	11	3	2	1	..	47	124	77	65	84	38
Février	..	1	38	15	..	1	..	1	57	113	56	53	95	50
Mars	5	18	29	23	4	2	3	1	39	124	85	52	61	31
Avril	4	5	15	16	1	2	..	3	74	120	46	31	67	62
Mai	2	10	18	9	4	4	2	3	72	124	52	27	52	58
Juin	5	12	18	9	2	3	5	6	60	120	60	27	45	50
Juillet	3	16	14	4	5	3	2	6	71	124	53	18	34	57
Août	1	7	9	21	7	5	3	4	67	124	57	30	53	54
Septembre	3	14	20	10	2	5	1	2	63	120	57	30	53	53
Octobre	3	10	28	19	1	2	1	4	56	124	68	47	69	45
Novembre	4	18	32	17	4	6	2	3	34	120	86	49	57	28
Décembre	1	13	41	25	1	1	2	1	39	124	85	66	78	32
Année	31	130	316	179	34	36	22	34	679	1.461	782	495	63	46

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[a] Par rapport au nombre des vents non calmes.

[b] Par rapport au nombre total des mesures.

TABLEAU X

VENT AU SOL À NOUMÉA À 12 HEURES DE 1935 À 1938

Mois	N	NE	E	SE	S	SW	W	NW	Calme	Total	Vents non calmes	Vents d'E et de SE (total)	Pourcentage des vents d'E et SE[a]	Pourcentage des vents calmes[b]
Janvier	1	4	21	42	30	20	2	..	4	124	120	63	53	3
Février	..	5	13	38	35	6	5	..	11	113	102	51	50	10
Mars	..	15	26	44	8	19	7	1	4	124	120	70	58	3
Avril	2	3	15	32	14	26	12	2	14	120	106	47	44	12
Mai	..	6	22	44	13	18	14	1	6	124	118	66	56	5
Juin	..	10	15	32	12	15	20	2	14	120	106	47	44	12
Juillet	1	2	21	35	15	20	21	2	7	124	117	56	49	6
Août	..	5	13	50	10	27	12	1	6	124	118	63	53	5
Septembre	..	3	13	57	13	35	5	1	3	120	117	70	60	2
Octobre	..	7	14	49	13	22	8	..	1	124	123	63	51	1
Novembre	..	8	13	51	16	28	4	..	..	120	120	64	52	0
Décembre	..	7	16	61	13	20	4	..	3	124	121	67	55	2
Année	4	75	202	535	192	256	114	10	73	1.461	1.388	727	53	5

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[a] Par rapport au nombre des vents non calmes.

[b] Par rapport au nombre total des mesures.

TABLEAU XI

VENT AU SOL À NOUMÉA À 17 HEURES DE 1935 À 1938

Mois	N	NE	E	SE	S	SW	W	NW	Calme	Total	Vents non calmes	Vents d'E et de SE (total)	Pourcentage des vents d'E et SE[a]	Pourcentage des vents calmes[b]
Janvier	3	2	30	44	22	9	3	..	11	124	113	74	65	9
Février	2	5	20	46	18	2	5	..	15	113	98	66	67	13
Mars	..	17	23	48	5	6	10	..	15	124	109	71	65	12
Avril	..	3	10	39	5	3	12	..	48	120	72	49	68	40
Mai	1	6	31	35	4	6	9	1	31	124	93	66	71	25
Juin	..	6	21	22	5	8	14	3	41	120	79	43	54	34
Juillet	1	4	22	32	10	8	16	1	30	124	94	54	58	24
Août	1	6	26	42	7	14	6	..	22	124	102	68	67	18
Septembre	..	5	12	47	7	10	8	1	30	120	90	59	66	25
Octobre	..	14	23	54	7	6	5	..	15	124	109	77	71	12
Novembre	..	8	27	43	7	14	4	2	15	120	105	70	67	13
Décembre	..	7	29	58	6	3	3	..	18	124	106	87	82	15
Année	8	83	274	510	103	89	95	8	291	1.461	1.170	784	67	20

[a] Par rapport au nombre des vents non calmes.

[b] Par rapport au nombre total des mesures.

TABLEAU XII

Fréquence des Vitesses de Vent à Nouméa à 7 Heures de 1935 à 1938 (Echelle Beaufort)

Mois	Force moyenne	Force 1	Force 2	Force 3	Force 4	Force 5	Force 6	Force 7	Force 8	Force 9	Total[a]
Janvier......	1.32	22	31	19	3	1	1	..	..	..	77
Février.....	0.96	18	28	5	5	..	..	..	..	..	56
Mars........	1.46	25	38	14	5	2	..	..	..	1	85
Avril........	0.78	12	21	11	2	..	..	..	..	..	46
Mai..........	0.79	20	21	8	3	..	..	..	..	..	52
Juin..........	0.90	20	32	6	2	..	..	..	..	..	60
Juillet.......	0.88	13	26	12	2	..	..	..	..	..	53
Août........	0.85	19	27	8	3	..	..	..	..	..	57
Septembre..	0.82	21	31	5	..	..	..	..	..	..	57
Octobre.....	1.06	25	32	8	2	1	..	..	..	..	68
Novembre...	1.30	27	48	10	1	..	..	..	..	..	86
Décembre...	1.38	25	41	13	5	1	..	..	..	..	85
Année.......	1.04	247	376	119	33	5	1	..	..	1	782

[a] Nombre des vents non calmes.

TABLEAU XIII

Fréquence des Vitesses de Vent à Nouméa à 12 Heures de 1935 à 1938 (Echelle Beaufort)

Mois	Force moyenne	Force 1	Force 2	Force 3	Force 4	Force 5	Force 6	Force 7	Force 8	Force 9	Total[a]
Janvier......	2.76	23	28	33	21	11	1	3	..	..	120
Février.....	2.23	23	29	35	9	6	..	..	..	..	102
Mars........	2.55	13	45	40	20	..	2	..	..	..	120
Avril........	1.87	37	32	30	6	1	..	..	..	..	106
Mai..........	2.10	27	47	38	5	1	..	..	..	..	118
Juin..........	1.92	22	47	33	3	..	1	..	..	..	106
Juillet......	2.12	25	41	45	6	..	..	..	..	..	117
Août........	2.22	24	43	40	10	1	..	..	..	..	118
Septembre..	2.32	16	53	38	10	..	..	..	..	..	117
Octobre.....	2.65	8	47	50	12	5	1	..	..	..	123
Novembre..	2.62	13	41	43	22	1	..	..	..	..	120
Décembre...	2.66	18	35	37	22	9	..	..	..	..	121
Année.......	2.34	249	488	462	146	35	5	3	..	..	1.388

[a] Nombre de vents non calmes.

TABLEAU XIV

Fréquence des Vitesses de Vent à Nouméa à 17 Heures de 1935 à 1938 (Echelle Beaufort)

Mois	Force moyenne	Force 1	Force 2	Force 3	Force 4	Force 5	Force 6	Force 7	Force 8	Force 9	Total[a]
Janvier	2.51	16	34	34	20	5	2	1	1	..	113
Février	2.11	16	39	29	13	1	..	..	..	..	98
Mars	2.15	18	42	36	10	2	..	..	1	..	109
Avril	1.37	15	28	22	7	..	..	..	..	..	72
Mai	1.77	13	51	22	6	1	..	..	..	..	93
Juin	1.31	27	26	24	2	..	..	..	..	..	79
Juillet	1.70	16	41	34	3	..	..	..	..	..	94
Août	1.70	32	36	28	5	1	..	..	..	..	102
Septembre	1.41	19	37	29	5	..	..	..	..	..	90
Octobre	1.99	25	36	41	5	2	..	..	..	..	109
Novembre	2.00	19	48	30	7	1	..	..	..	..	105
Décembre	2.11	20	35	35	13	3	..	..	..	..	106
Année	1.84	236	453	364	96	16	2	1	2	..	1.170

[a] Nombre de vents non calmes.

TABLEAU XV

Nebulosité à Nouméa (Moyennes et Fréquences) de 1935 à 1938

Mois	Nébulosité moyenne	Ciel clair 0 à 2/10	Ciel peu nuageux 2 à 5/10	Ciel nuageux 5 à 8/10	Ciel couvert 8 à 10/10	Total
Janvier	4,8	32	38	30	24	124
Février	4,8	24	37	37	15	113
Mars	6,3	18	28	33	45	124
Avril	6,3	9	35	37	39	120
Mai	5,0	27	37	40	20	124
Juin	5,2	23	35	34	28	120
Juillet	5,4	19	34	40	31	124
Août	4,8	30	33	39	22	124
Septembre	4,3	23	52	30	15	120
Octobre	4,2	32	37	41	14	124
Novembre	4,4	29	37	39	15	120
Décembre	4,9	23	43	32	26	124
Année	5,0	289	446	432	294	1461

TABLEAU XVI

Visibilités Moyennes à Nouméa aux Heures Synoptiques, de 1935 à 1938

Mois	Moyenne 7 H[a]	Moyenne 12 H[a]	Moyenne 17 H[a]	Moyenne générale[a]
Janvier	20,7	27,1	25,8	24,5
Février	25,2	28,2	27,1	26,8
Mars	16,8	18,7	15,3	16,9
Avril	16,3	19,5	14,5	16,7
Mai	12,7	15,5	13,1	13,8
Juin	12,3	14,3	11,8	12,8
Juillet	16,6	20,9	17,5	18,3
Août	15,2	17,6	14,1	15,3
Septembre	18,7	20,6	19,1	19,4
Octobre	19,8	23,0	15,7	19,5
Novembre	21,1	21,3	15,6	19,3
Décembre	22,1	21,3	16,0	19,8
Année	18,1	20,7	17,1	18,6

[a] En kilomètres et dixièmes.

TABLEAU XVII

Visibilité à Nouméa à 7 Heures (Fréquences) de 1935 à 1938

Mois	< 1 K.	1 à 2 K.	2 à 4 K.	4 à 10 K.	10 à 20 K.	20 à 50 K.	> 50 K.	Total
Janvier	0	0	1	9	26	73	15	124
Février	0	1	0	6	24	60	22	113
Mars	0	2	5	31	27	39	20	124
Avril	1	1	2	22	38	44	12	120
Mai	0	0	2	24	53	37	8	124
Juin	0	2	5	25	45	37	6	120
Juillet	0	0	4	15	37	62	6	124
Août	0	2	4	12	44	53	9	124
Septembre	0	0	4	8	32	61	15	120
Octobre	0	1	0	8	43	54	18	124
Novembre	0	0	1	8	32	64	15	120
Décembre	0	2	1	11	27	69	14	124
Année	1	11	29	179	428	653	160	1.461

TABLEAU XVIII

VISIBILITÉ À NOUMÉA À 12 HEURES (FRÉQUENCES) DE 1935 À 1938

Mois	< 1 K.	1 à 2 K.	2 à 4 K.	4 à 10 K.	10 à 20 K.	20 à 50 K.	> 50 K.	Total
Janvier	0	1	0	2	18	79	24	124
Février	1	0	0	5	6	78	23	113
Mars	1	1	1	15	39	47	20	124
Avril	0	2	1	4	42	60	11	120
Mai	0	0	4	16	46	48	10	124
Juin	0	1	1	18	44	48	8	120
Juillet	0	0	1	4	34	79	6	124
Août	0	0	3	8	32	74	7	124
Septembre	0	0	1	5	25	76	13	120
Octobre	0	0	0	4	22	92	6	124
Novembre	0	0	2	4	25	71	18	120
Décembre	0	0	2	11	21	70	20	124
Année	2	5	16	96	354	822	166	1.461

TABLEAU XIX

VISIBILITÉ À NOUMÉA À 17 HEURES (FRÉQUENCES) DE 1935 À 1938

Mois	< 1 K.	1 à 2 K.	2 à 4 K.	4 à 10 K.	10 à 20 K.	20 à 50 K.	> 50 K.	Total
Janvier	0	1	1	6	18	75	23	124
Février	0	1	1	6	10	72	23	113
Mars	5	3	5	25	34	42	10	124
Avril	0	2	6	15	46	39	12	120
Mai	0	0	1	25	50	41	7	124
Juin	0	1	2	27	40	43	7	120
Juillet	0	0	1	10	40	67	6	124
Août	0	0	1	14	53	51	5	124
Septembre	0	1	0	16	37	62	4	120
Octobre	0	0	0	14	52	56	2	124
Novembre	0	0	3	12	46	55	4	120
Décembre	0	1	1	17	44	47	14	124
Année	5	10	22	187	470	650	117	1.461

TABLEAU XX

NOMBRE MOYEN D'OBSERVATIONS DE BROUILLARD ET DE BRUME PAR AN, DE 1935 À 1938

Mois	Brouillard[a]				Brume[b]			
	7 h.	12 h.	17 h.	Total	7 h.	12 h.	17 h.	Total
Janvier	0,0	0,0	0,0	0,0	0,3	0,3	0,5	1,1
Février	0,0	0,3	0,0	0,3	0,3	0,0	0,5	0,8
Mars	0,0	0,3	1,3	1,6	1,8	0,5	2,0	4,3
Avril	0,3	0,0	0,0	0,3	0,8	0,8	2,0	3,6
Mai	0,0	0,0	0,0	0,0	0,5	1,0	0,3	1,8
Juin	0,0	0,0	0,0	0,0	1,8	0,5	0,8	3,1
Juillet	0,0	0,0	0,0	0,0	1,0	0,3	0,3	1,6
Août	0,0	0,0	0,0	0,0	1,5	0,8	0,3	2,6
Septembre	0,0	0,0	0,0	0,0	1,0	0,3	0,3	1,6
Octobre	0,0	0,0	0,0	0,0	0,3	0,0	0,0	0,3
Novembre	0,0	0,0	0,0	0,0	0,3	0,5	0,8	1,6
Décembre	0,0	0,0	0,0	0,0	0,8	0,5	0,5	1,8
Année	0,3	0,6	1,3	2,2	10,4	5,5	8,0	24,2

[a] Visibilité inférieure à 1 K.
[b] Visibilité inférieure à 4 K.

TABLEAU XXI

ORAGES ET MANIFESTATIONS ELECTRIQUES À NOUMÉA DE 1935 À 1938

Mois	Nombre d'orages en 4 ans[a]	Nombre moyen par an	Pourcentage mensuel
Janvier	6	1,50	16,7
Février	9	2,25	25,0
Mars	3	0,75	8,3
Avril	3	0,75	8,3
Mai	2	0,50	5,6
Juin	1	0,25	2,8
Juillet	0	0,00	00,0
Août	1	0,25	2,8
Septembre	1	0,25	2,8
Octobre	1	0,25	2,8
Novembre	2	0,50	5,6
Décembre	7	1,75	19,4
Année	36	9,00	100,0

[a] Orages, éclairs seuls, tonnerres seuls.

TABLEAU XXII

Répartition Mensuelle des Cyclones Observés en Nouvelle-Calédonie de 1847 à 1939

Mois	Nombre observé pour chaque mois	Pourcentage
Janvier	14	23
Février	16	27
Mars	15	25
Avril	3	5
Mai	1	2
Juin	0	0
Juillet	2	3
Août	0	0
Septembre	1	2
Octobre	2	3
Novembre	0	0
Décembre	6	10
Année	60	100

NOTE SUR LE SERVICE METEOROLOGIQUE COLONIAL FRANÇAIS DANS LE PACIFIQUE

Le Service Météorologique Colonial Français fut créé en 1929. Dans ses attributions entrent, non seulement les études et applications relatives à la Météorologie proprement dite, mais aussi tout ce qui touche à la Physique du Globe : électricité atmosphérique, magnétisme terrestre, volcanologie, etc. . . . Il comprend un cadre général d'ingénieurs recrutés, soit au concours, soit sur titres, parmi les élèves diplômés des grandes écoles de l'Etat et les licenciés ès-sciences, un cadre général d'assistants et des cadres locaux d'agents indigènes spécialisés.

Indochine

Antérieurement à la création de ce service, un gros effort avait été déjà fait en Extrême-Orient. Dès 1902, le Gouverneur Général P. Doumer avait fondé l'Observatoire Central et le Service Météorologique de l'Indochine.

La création en 1929 d'un Service Météorologique relevant du Ministère des Colonies permit au Service Météorologique de l'Indochine de prendre un essor nouveau. A cette époque se place la création des premières grandes lignes aériennes reliant l'Europe à l'Extrême-Orient; les exigences de la protection météorologique de l'aviation posent des problèmes nouveaux auxquels une solution doit être apportée d'urgence. Depuis lors, et malgré les difficultés d'ordre financier auxquelles il dut faire face, le Service Météorologique de l'Indochine connut une activité croissante—sans doute, celle-ci fut-elle, au cours des dernières années, à peu près totalement absorbée par la protection de la navigation aérienne et de la navigation maritime, tâche d'importance capitale exigeant du personnel un effort det ous les instants, beaucoup de compétence et de dévouement.

Réseau des stations.—A l'heure actuelle, le réseau météorologique indochinois comprend : 8 stations principales ; 31 stations de premier ordre, toutes tenues par du personnel spécialisé relevant de la Direction du Service à Hanoï et en liaison, soit par fil, soit par T. S. F. avec le Service Central à Hanoï et avec le centre du réseau Sud à Saigon ; 20 stations dites aéronautiques, confiées à du personnel militaire ayant reçu une formation préalable au Service Météorologique ; 57 stations, dites climatologiques, la plupart confiées aux Services de l'Agriculture du Gouvernement Général, aux stations de l'Institut de recherches agronomiques et aux grandes Sociétés agricoles de la Colonie ; 450 stations pluviométriques.

Emissions radiotélégraphiques.—Le Service Météorologique de l'Indochine émet :

1°—5 fois par jour des météogrammes dits "nationaux" simultanément sur 2 postes à ondes courtes, de longueur d'onde et de puissance différentes. Les météogrammes sont plus particulièrement destinés aux Services étrangers avec lesquels collabore l'Indochine : Chine, Hongkong, Philippines, Malaisie, Siam, Indes Néerlandaises.

2°—1 fois par jour, un météogramme collectif d'Extrême-Orient, plus spécialement destiné aux Services Météorologiques européens. Ce météogramme est, à de rares exceptions près, reçu à Paris dans de bonnes conditions.

3°—1 fois par jour, un bulletin météorologique en clair, à l'usage de la navigation maritime et, en période de typhons, des avis aussi nombreux qu'il est nécessaire, très souvent de deux en deux heures, parfois d'heure en heure.

Protection de la navigation aérienne.—Il a été dit plus haut que l'activité du Service Météorologique de l'Indochine est, à l'heure présente, en grande partie absorbée par la protection de la navigation aérienne. La météorologie indochinoise doit, en effet, satisfaire aux besoins croissants de l'aviation militaire de la Colonie et à ceux, également croissants, des lignes aériennes régulières françaises et étrangères qui survolent l'Indochine eu y font escale :

Ligne Air-France Marseille-Hanoi-Hongkong.
Ligne Imperial Airways Bangkok, Hongkong (bretelle de la ligne impériale Londres-Brisbane).
Ligne Eurasia-Yunnanfou-Hanoï.
Ligne C. N. A. C. Tchongking-Hanoï.
Ligne K. L. M. I. Batavia-Singapour-Saigon.

En plus des prévisions remises au départ des avions, le Service Météorologique est en mesure de transmettre, rapidement et aussi souvent qu'il est nécessaire (généralement d'heure en heure, parfois de quart d'heure en quart d'heure) aux avions en vol, les renseignements qui intéressent le ou les parcours à survoler.

Climatologie.—Dans le domaine de la climatologie, le Service Météorologique de l'Indochine travaille en liaison étroite avec les Services ou entreprises intéressés. C'est lui qui, en particulier, fournit toute la documentation d'ordre climatologique nécessaire à l'exécution des grands travaux d'hydraulique agricole, travaux qui, au cours des dernières années, ont été poursuivis à un rythme accéléré. En période de crues, il communique aux Services et Administrations intéressés des renseignements quotidiens et des prévisions relatifs à l'importance des précipitations.

Il fait paraitre des Annales où figurent, pour toutes les stations du réseau, la documentation dont les intéressés peuvent avoir besoin.

Liaison avec l'organisation météorologique internationale.—Liaison étroite également avec l'O. M. I. le chef du Service Météorologique de l'Indochine était, l'an passé encore, membre du Comité Météorologique International et Président de la Commission régionale II, dite d'Extrême-Orient. On trouvera dans les publications de l'O. M. I. les procès-verbaux de la Conférence qu'il réunit à Hongkong en Janvier 1937 et à laquelle participèrent 33 délégués et invités des pays suivants : Indes, Siam, Indo-Chine, Chine, Malaisie, Iles Philippines, Indes Néerlandaises et Australie.

Branches autres que la météorologie.—L'Observatoire de Phu-Lien, près de Haiphong, qui fut jusqu' à la fin de 1938 le Siège du Service Central Météorologique possède, depuis 1927, une installation méridinne et un service horaire très convenablement outillés. Il prit part, en 1933, à la deuxième opération mondiale de détermination des longitudes, organisée par l'Union Géodésique et Géophysique Internationale.

L'Observatoire de Phu-Lien possède également une station de séismologie dont la collaboration est fort appréciée du Bureau International de Séismologie de Strasbourg. Il publie un bulletin séismique largement diffusé.

Etudes projétées.—L'accroissement récent de l'effectif du personnel européen du Service Météorologique de l'Indochine permet d'envisager l'application de son activité à des branches de la Physique du Globe auxquelles, par la force même des choses, il avait dû, jusqu'ici, rester étranger.

Etudes d'électricité atmosphérique et de magnétisme terrestre sont, d'ores et déjà, inscrites au programme des travaux à entreprendre avec l'appui financier du Service Central de la Recherche Scientifique. On espère aussi que, malgré l'importance des dépenses à engager, il sera possible à la Colonie de répondre prochainement aux vœux émis par l'Organisation Météorologique Internationale en matière de radiosondages.

ETABLISSEMENTS FRANÇAIS DE L'OCEANIE

La création d'un service météorologique dans les Etablissements Français de l'Océanie date de 1931. Malgré les très grosses difficultés auxquelles il eut à faire face, le Chef du Service, à qui les autorités locales fournissent tout l'appui compatible avec des ressources budgétaires très limitées, a pu mettre sur pied une organisation qui, encore que très imparfaite, permet de satisfaire aux besoins essentiels de la navigation maritime et de l'aviation. L'effort commencé se poursuivra au cours des années à venir. Le réseau des stations, actuellement encore quelque peu embryonnaire, sera développé; les liaisons intérieures et les liaisons avec les organismes étrangers voisins seront améliorées de façon telle que la Météorologie des Etablissements Français de l'Océanie soit en mesure de répondre à tous les désirs qu'exprimeront les Compagnies de Navigation aérienne, le jour où les lignes régulières emprunteront cette région du globe.

Actuellement, le réseau du Service Météorologique colonial français en Océanie comprend :

1°—Un observatoire central près de Papeete (Tahiti).

2°—Six stations de premier ordre à Oturea, Atuona, Taiohu, Rikitea, Tubua, et Makatoa.

3°—Deux stations de second ordre à Afaahiti (Tahiti) et Rapa.

L'observatoire de Tahiti possède une station séismologique. Les enregistrements sont régulièrement dépouillés et publiés.

NOUVELLE-CALÉDONIE

Un service météorologique a été tout récemment créé en Nouvelle-Calédonie. Il commencera à fonctionner dans le courant de l'année. L'ingénieur météorologiste, ancien élève de l'Ecole Polytechnique, qui en a été chargé, a servi pendant trois ans à l'Office National Météorologique de France et, de ce fait, est parfaitement au courant des méthodes les plus récentes de la Météorologie Aéronautique.

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N.B.—Les Annales de Physique du Globe de la France d'Outre-Mer sont éditées chez Larose, 11 rue Victor Cousin, Paris 5°.

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